1996-06

A two-cubed experiment to examine the effects of information completeness, work load, and fast patrol boat command and control in the littorals utilizing the wargame simulation : Batman & Robin

Vodantis, Nicholas K.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/9096

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

A TWO-CUBED EXPERIMENT TO EXAMINE THE EFFECTS OF INFORMATION COMPLETENESS, WORK LOAD, AND FAST PATROL BOAT COMMAND AND CONTROL IN THE LITTORALS UTILIZING THE WARGAME SIMULATION: *BATMAN & ROBIN*

by

Nicholas K. Vodantis

June 1996

Principal Advisor: Gary R. Porter
Associate Advisor: William G. Kemple

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE June 1996

3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE A TWO-CUBED EXPERIMENT TO EXAMINE THE EFFECTS OF INFORMATION COMPLETENESS, WORK LOAD, AND FAST PATROL BOAT COMMAND AND CONTROL IN THE LITTORALS UTILIZING THE WARGAME SIMULATION: *BATMAN & ROBIN*

5. FUNDING NUMBERS

6. AUTHOR(S) Nicholas K. Vodantis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Fast Patrol Boats were considered a negligible threat when the U.S. Navy focused on blue water operations away from shore. Now that the Navy's focus has shifted to the littorals, where these ships patrol, the Fast Patrol Boat's potential as a credible adversary is gaining acceptance. Moreover, the threat may be greatly enhanced if Fast Patrol Boats employ Commercial Off-The-Shelf Command and Control equipment to coordinate their efforts. This paper presents the design and results of a wargaming experiment conducted with *Batman & Robin* at the Naval Postgraduate School to examine this issue. The research question is how would U.S. Navy Surface Action Groups perform against Fast Patrol Boats equipped with Commercial Off-The-Shelf Command and Control equipment which enables these comparatively unsophisticated ships to conduct coordinated attacks. The experiment also looked at two other factors: Surface Action Group work load, which might exacerbate the offensive capability of Fast Patrol Boats conducting coordinated attacks with advanced Command and Control; and the quality of information our Surface Action Groups are provided which could likewise play a pivotal role in a confrontation or engagement. A two-cubed factorial experiment was conducted to test seven hypotheses. Data were collected on ten performance measures for 128 trials total. Significant results were obtained for three factors and three interactions. Operational explanations are provided.

14. SUBJECT TERMS Surface Action Groups, Command and Control, Work Load, Fast Patrol Boats, Frequency Plots, Box Plots, ANOVA, Batman & Robin Information Completeness

15. NUMBER OF PAGES 102

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

Approved for public release; distribution is unlimited.

A TWO-CUBED EXPERIMENT TO EXAMINE THE EFFECTS OF INFORMATION COMPLETENESS, WORK LOAD, AND FAST PATROL BOAT COMMAND AND CONTROL IN THE LITTORALS UTILIZING THE WARGAME SIMULATION: *BATMAN & ROBIN*

Nicholas K. Vodantis
Lieutenant, United States Navy
B.S., The Pennsylvania State University, 1987

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE
IN
SYSTEMS TECHNOLOGY

from the

NAVAL POSTGRADUATE SCHOOL
June 1996

ABSTRACT

Fast Patrol Boats were considered a negligible threat when the U.S. Navy focused on blue water operations away from shore. Now that the Navy's focus has shifted to the littorals, where these ships patrol, the Fast Patrol Boat's potential as a credible adversary is gaining acceptance. Moreover, the threat may be greatly enhanced if Fast Patrol Boats employ Commercial Off-The-Shelf Command and Control equipment to coordinate their efforts. This paper presents the design and results of a wargaming experiment conducted with *Batman & Robin* at the Naval Postgraduate School to examine this issue.

The research question is how would U.S. Navy Surface Action Groups perform against Fast Patrol Boats equipped with Commercial Off-The-Shelf Command and Control equipment which enables these comparatively unsophisticated ships to conduct coordinated attacks. The experiment also looked at two other factors: Surface Action Group work load, which might exacerbate the offensive capability of Fast Patrol Boats conducting coordinated attacks with advanced Command and Control; and the quality of information our Surface Action Groups are provided which could likewise play a pivotal role in a confrontation or engagement.

A two-cubed factorial experiment was conducted to test seven hypotheses. Data were collected on ten performance measures for 128 trials total. Significant results were obtained for three factors and three interactions. Operational explanations are provided.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Fast Patrol Boats (FPB) have always been an effective platform for littoral warfare. With today's advanced commercial off-the-shelf command and control (C^2) technology, the threat FPBs pose to the U.S. Navy could drastically increase. Effective C^2 would enable FPBs to conduct coordinated attacks using sophisticated tactics that could saturate a Surface Action Group's (SAG) defenses.

In addition, the small size and high speed of FPBs combine to complicate intelligence gathering and increase the work load on SAG operators trying to maintain an accurate surface picture of the littoral environment.

The main research question is the effect that coordinated attacks by FPBs, employing advanced C^2, will have in an engagement with a U. S. Navy SAG operating in littoral seas. Also of interest are the effects, and their interactions with the main effect, of two elements which accompany the presence of FPBs and a littoral operating area: increased work load and incomplete information.

FPB C^2 was modeled by varying the tactical coordination of the FPBs between high and low. High coordination was modeled by three concurrent waves of attacks of FPBs with most of the FPBs in a restricted emissions status. Low coordination was modeled by sequential attacks of FPBs. Work load was modeled by varying the number of neutral ships in the vicinity of the attack. High work load scenarios contained 24 neutral ships in the operating area while low work load scenarios contained only nine. Information completeness was modeled by varying the completeness of the maritime intelligence reports that the SAG received during the trial. High information completeness was represented by providing the subjects with a ratio of hostile ships in each threat sector to the total number of ships in the threat sector. Low information completeness was represented by only providing the total number of ships in each threat sector.

A two-cubed factorial experiment was conducted to test the seven hypotheses (three main hypotheses plus four secondary hypotheses examining all possible interactions). Eight Persian Gulf scenarios were developed on the wargame simulator *Batman & Robin* as a

context for the experiment. The wargame has two modes of operation: *Batman*, where scenarios are executed, and *Robin,* where scenarios are developed. Each scenario represented a unique combination of the three factors at two levels. Sixteen subjects from the Naval Postgraduate School (NPS) participated in the experiment. Each subject played each scenario using *Batman* once. Trials (8 x 16 = 128) were run at four times real time and were completed in 38 minutes.

In each scenario the Blue force SAG was comprised of three combatants and five helicopters. Red forces were comprised of nine FPBs. The subjects controlled the Blue order of battle. Red order of battle was scripted in *Robin* during scenario development but could deviate from the script in *Batman* according to its pre-programmed artificial intelligence.

Ten performance measures were automatically generated by *Batman & Robin* at the end of each trial and were used to test the hypotheses. The data analysis plan includes use of frequency plots, box plots, MANOVA, univariate ANOVA, interaction plots, residual plots, and non-paramtetric statistics to assess the data. A significance level of $\alpha = 0.05$ was established to test all null hypotheses.

Hypotheses tests show significant results in the main hypotheses and several interaction hypotheses over a broad range of performance measures. The most important findings are condensed as follows:

- When the FPBs had high C^2, fewer were detected, however, of those detected the range of detection was greater.
- When the FPBs had high C^2, fewer were destroyed, but those that were destroyed were done so at a greater range.
- The range at which the FPBs were detected and destroyed both decreased when work load increased.
- With complete information the FPBs were destroyed at a greater range.

ACKNOWLEDGMENT

The author would like to acknowledge Dr. Pat-Anthony Federico of the Naval Personnel Research and Development Center for providing the wargame simulation *Batman & Robin* which made this experiment possible. His technical support throughout the experiment is greatly appreciated. In addition, the guidance and expertise of Professor Gary Porter and Professor William Kemple of the Naval Postgraduate School was instrumental in translating a real world concern from a concept to an executable experiment, and ultimately, a complete thesis.

Finally, a special thanks to my wife, Dana, for her support and patience over the entire course of this project.

I. INTRODUCTION

This chapter discusses the purpose and scope of the experiment and closes with the organization of the rest of the thesis.

A. PURPOSE

This section lays out the purpose of the experiment by describing the problem in real world terms. This leads to a statement of the research question, and the approach taken to examine the problem. The three main factors and their levels are discussed with anticipated results provided.

1. Real World Problem

As more and more navies turn away from *blue water* naval strategies that necessitate sophisticated and expensive multipurpose combatants and toward regional and littoral dominance, the fast patrol boat's utility as a cost effective naval platform for littoral warfare increases [Ref. 1]. Coupled with the availability of commercial off-the-shelf (COTS) command and control (C^2) technology, fast patrol boats present a unique challenge to the U.S. Navy and the traditional maritime powers still operating large naval combatants built for blue water operations [Ref. 2].

Moreover, the U.S. Navy frequently deploys Surface Action Groups or SAGs (task groups comprised primarily of combatants) throughout the littoral regions of the world. Despite the fact that SAGs have organic helicopter assets, without the protection of an aircraft carrier's air wing they are vulnerable to stealthy, formidably armed fast patrol boats (FPB).[1]

The FPB's small size and high speed combine to complicate intelligence gathering. In addition, U.S. Naval combatants are not optimized to track, target and neutralize small, fast surface platforms, nor can they still assume the dominant tactical advantage inherent

---

1 The helicopter asset in mention is the LAMPS MK III SH-60B Seahawk. Currently the Seahawk has no lethal ASUW capability. The SH-60B Block I upgrade will have a forward firing weapon's capability. It is scheduled for fleet introduction by 1998 [Ref. 3].

with superior C^2 [Ref. 4]. Still employing forces specifically designed for *blue water* warfare, the U.S. Navy is caught in the middle of this shifting paradigm and appears slow to react to the FPB threat in the littorals [Ref. 5].

2. Research Question

FPBs already possess speed and stealth advantages over most combatants. The main research question concerns the effect that coordinated saturation attacks by FPBs, employing advanced C^2, will have on an engagement with U. S. SAGs operating in littoral seas. Also of interest are the effects of increased workload and incomplete intelligence, both of which accompany the presence of FPBs in a littoral operating area, and their interactions with the main effect.

3. Approach

A three factor experiment was constructed involving human decision makers. All factors were presented at two levels, high and low, resulting in a two cubed factorial experiment. The experiment was designed and executed on the *Battle Management Assessment System and Raid Originator Bogie Ingress* wargame, more commonly called *Batman and Robin* (B&R). The wargame has two operational interfaces. In *Robin*, scenarios are developed and edited. In *Batman*, scenarios are executed and operational performance is measured. Eight different scenarios were generated in *Robin* to present all combinations of levels of factors. Each scenario was then administered to 16 Naval Postgraduate School (NPS) officer students using *Batman*, for a total of 128 trials. The geographic location of each scenario was identical: the Persian Gulf, between the Straits of Hormuz and Bahrain. Red forces were comprised of nine OSA II FPBs. A three combatant SAG composed of one Kidd class destroyer, two Spruance class destroyers, and five SH-60B Seahawk helicopters constituted Blue forces. All forces were armed and equipped realistically. The three design variables or factors were:

a. Information Completeness

For high information completeness, the maritime intelligence was represented by a ratio of hostile ships in a threat sector to the total number of ships in the

threat sector. For low information completeness, only the total number of ships per threat sector was given.

b. Workload

High workload scenarios were characterized by 24 neutral ships and nine hostile FPBs in the operating area. Low work load scenarios had nine neutral ships and nine hostile FPBs in the operating area.

c. FPB C^2

The third factor was FPB C^2. This is not only the primary factor of interest, but also the original impetus for the experiment. The analysis will focus on this factor. Two levels of FPBs C^2 were achieved by varying their tactical coordination between high and low. High coordination was modeled by three concurrent waves of attacks of FPBs. For this case, seven of the nine FPBs were in restricted emission control (EMCON) status with the remaining two in an unrestricted EMCON status. It was assumed that coordinated attackers would share information about their enemy, the U.S. SAG in this case, and thus require fewer emissions. Low coordination was modeled by sequential attacks of FPBs with only two of the nine FPBs in a restricted EMCON status and the remaining seven emitting.

4. Anticipated Results

The hypothesized results were that friendly (Blue) forces would perform better when the following occurred:

- Information or intelligence reports were complete.
- The ship's combat team was experiencing low workload conditions.
- Incoming attacks were uncoordinated (sequential) vice coordinated (concurrent).

B. SCOPE OF THE EXPERIMENT

The complexity of the scenarios for this experiment was limited due to time constraints and the varied backgrounds and limited operational experience of some of the subjects.[2] Blue Force resources were initialized in the same manner for every scenario and for every subject. This standardization was done to reduce the risk of subjects with operational experience gaining an advantage by relying on their expert knowledge to position their forces. In addition, certain artificialities were accepted in the interest of practicality and usability. For instance, the wargame was run at a speed of 4:1 (i.e., 4 seconds of simulated time = 1 second of real time). Therefore a 152 minute simulated event could be compressed into 38 minutes of real time. All scenarios were constructed similarly except to allow for the systematic introduction of both levels of all factors. Scenarios were constructed to *appear* different to the subjects without affecting essential traits. This diminished the chance of subjects relying on prior scenario knowledge to *game* the scenario instead of making decisions based on current scenario developments.

C. ORGANIZATION

The remainder of the thesis is organized as follows: Chapter II introduces the design of the experiment including the set-up, subjects, hypotheses, assumptions, statistical design of the experiment, and measures. Chapter III describes the data, how the raw data were collected and transformed, the data coding scheme, and data reduction phase. Chapter IV presents the data analysis plan, results of the data analysis and demographic information on the subjects. Chapter V presents conclusions including results of hypotheses tests and their real world meanings. Finally, Chapter VI offers recommendations to change, improve upon, and extend this experiment for the future.

---

[2] The experiment had to be set-up, played, and recorded in the 50 minute class period.

II. EXPERIMENTAL DESIGN

This chapter discusses experimental set-up and presents the seven hypotheses that are associated with this two-cubed experiment. In addition the assumptions, statistical design, and measures of the experiment are explained.

A. SET - UP

In this section the software, hardware, and subjects are discussed. B&R was chosen because of the ease and speed with which scenarios could be generated and modified. It addition, it has a superior graphical user interface and artificial intelligence which allows pre-scripted Red forces to deviate from the script in *Batman* and behave opportunistically. Finally, B&R has an automatic data collection capability which is very useful in the data collection phase.

1. Software and Hardware

B&R software was obtained from the creator of the wargame, Dr. Pat-Anthony Federico, at the Naval Personnel Research and Development Center (NPRDC), San Diego. It is written in the "C" programming language. B&R was installed in the NPS Systems Technology Lab (STL) on five Sun Sparc-20 stations and runs in a UNIX Solaris 2.5 environment. All scenarios were created in *Robin* on one Sparc station and ported to the other four to ensure standardization. Each subject executed each scenario in *Batman* independently of other subjects. B&R is not capable of running in a multi-player networked configuration.

2. Subjects

Sixteen officers participated as subjects in the experiment. Before the experimental trials commenced, all were given a 50 minute standardization overview brief of: SAG tactics, platform capabilities, sensor and weapon performance parameters, weapon status and weapon posture meanings, and B&R rules. This was done for standardization purposes and in an effort to mitigate learning effects. Each subject was administered two practice trials followed by the eight experimental trials in which data was collected. During the

practice trials, subjects received one-on-one instruction on B&R from trained proctors. All trials were completed during a ten day period due to course requirement constraints at NPS. Subjects were limited to three trials per day to preclude fatigue. Subjects were not permitted to discuss their trials with other subjects before, during, or after trials. The experiment was conducted in a controlled environment with physical dividers placed on both sides of each subject's computer station. Demographic information was collected on all of the subjects for future stratification analysis (see Chapter IV.B.4. for more information).

B. HYPOTHESES

Ten performance measures (PMs) or dependent variables were recorded for each trial. For a description of the PMs see Section G. The following hypotheses were tested for each PM:

- $\mathbf{H_{01}}$: Information Completeness has no impact on SAG performance.
- $\mathbf{H_{a1}}$: Information Completeness impacts SAG performance.
- $\mathbf{H_{02}}$: Work Load has no impact on SAG performance.
- $\mathbf{H_{a2}}$: Work Load impacts SAG performance.
- $\mathbf{H_{03}}$: FPB C^2 has no impact on SAG performance.
- $\mathbf{H_{a3}}$: FPB C^2 impacts SAG performance.
- $\mathbf{H_{04}}$: The combined effect of Information Completeness and Work Load has no impact on SAG performance.
- $\mathbf{H_{a4}}$: The combined effect of Information Completeness and Work Load impacts SAG performance.
- $\mathbf{H_{05}}$: The combined effect of Information Completeness and FPB C^2 has no impact on SAG performance.
- $\mathbf{H_{a5}}$: The combined effect of Information Completeness and FPB C^2 impacts SAG performance.

- H_{06}: The combined effect of Work Load and FPB C^2 has no impact on SAG performance.

- H_{a6}: The combined effect of Work Load and FPB C^2 impacts SAG performance.

- H_{07}: The combined effect of Information Completeness, Work Load and FPB C^2 has no impact on SAG performance.

- H_{a7}: The combined effect of Information Completeness, Work Load and FPB C^2 impacts SAG performance.

The significance level for null hypotheses rejection was set at *alpha* = 0.05. For convenience, these hypotheses are repeated in Appendix I.

C. ASSUMPTIONS

Four assumptions were made at the outset of the trials:

- Scenario outcomes represent the subject's ability to act on or react to the cues displayed by *Batman*.

- The ten performance measures (dependent variables) chosen from *Batman's* automatic data collection capability adequately identified the impact or influence of the factors (independent variables) and their interactions on the outcome of each scenario.

- The subjects' performance will be normally distributed and all populations will have the same variance.

- The scenarios are designed to measure the subjects' performance over the dynamic range of the performance curve.

D. STATISTICAL DESIGN OF THE EXPERIMENT

The experiment was counter-balanced to negate any learning effect remaining after the practice trials. The two-cubed design of the experiment yielded eight unique scenarios. Using 16 subjects and a completely randomized block design with 2 replications yielded an 8 x 16 output matrix. To construct the design matrix, the scenario type, order of scenario presentation and subject's assignment to a scenario presentation were all randomized. This triple randomization was accomplished using one 8 x 8 Latin Square for rows 1 - 8; the

Latin Square was composed of the letters a-h. A duplicate Latin Square was then inverted and used to create rows 9-16. Using 'APL2' programming language, unique random numbers were randomly assigned to the eight columns and then ordered. The same process was carried out for the 16 rows. Since the initial scenario numbering scheme was a function of the original order of generation and included numbers greater than 8, the scenarios were renumbered arbitrarily from 1-8. Those numbers were then randomized and assigned the letters a-h. As a last step, we used a manual random number generator to randomly assign the subjects to the rows. B&R has a utility function enabling the administrator to assign subjects to classes, scenarios to tests, and finally, classes to tests. Assignments were based on the outcome of the counter-balancing process. This function minimized the chance of error inherent with administering 160 trials (32 training and 128 experimental trials).

E. MEASURES

B&R's automatic data collection feature allowed 81 performance measures (PMs) or dependent variables to be collected after each trial. The 81 PMs are divided into two broad categories: Blue Forces' performance vs. Red Forces, and Red Forces' performance vs. Blue Forces. Each of these two broad categories is further divided into 3 sub-categories: air forces vs. surface, surface forces vs. surface, and combined air/surface forces vs. surface. Not all 81 PMs were applicable to this experiment. After a winnowing process the data was reduced to 10 PMs. Of the 10 PMs selected the first five measure Blue Forces' performance and the second five measure Red Forces' performance. The PMs used are defined as follows:

- **BAFP 1:** FPBs detected by Blue Air (%).
- **BAFP 2:** Average range (measured from nearest Blue force ship) at which FPBs were first detected by Blue Air (nm.).
- **BSP 3:** FPB's destroyed by Blue Surface (%).
- **BSP 4:** Average range (measured from nearest Blue force ship) at which FPBs were destroyed by Blue Surface (nm.).

- **BAFP 12:** Number of TAO weapon assignments (count).[3]

- **A 1:** Blue Air detected by the FPBs (%).

- **S 1:** Blue Surface detected by the FPBs (%).

- **A 2:** Average range (measured from nearest FPB) at which Blue Air was first detected by the FPBs (nm.).

- **S 2:** Average range (measured from nearest FPB) at which Blue Surface was first detected by the FPBs (nm.).

- **A 3:** Blue Air destroyed by the FPBs (%).

---

[3] Blue forces had to utilize the TAO function in order to fire their weapons and engage Red forces. This number represents the number of salvos launched by the operator per trial.

III. DATA DESCRIPTION

This chapter discusses the data collection and transformation process, the data coding scheme, and the data reduction phase.

A. DATA COLLECTION AND TRANSFORMATION

Although B&R calculated values for the PMs automatically, hardware limitations prohibited the automatic transfer of data to a file. Instead, each subject manually recorded their performance data displayed on the monitor to the PM data collection sheet at the end of each scenario. The large number of subjects participating at a given time precluded quality control while the subjects were recording their data. The information was then manually entered into Excel®. Before any data manipulations were performed, the data were put through a rigorous quality control process to check for data input errors. Data reduction was then performed and the data ported from Excel into Minitab® for statistical analysis. Once the data were in Minitab it was checked again for accuracy.

B. EXAMPLES OF RAW DATA

Appendix A contains an example of a subject's PM data collection sheet (a PM sheet was generated after each trial). Notice that all 81 possible PMs were recorded on the PM data collection sheet. This was done so the data could be recorded quickly and accurately. As stated previously, only 10 PMs were actually used in the subsequent analysis. Appendix B contains a sample of the master data spreadsheet. The spreadsheet contains data for each of the 16 subjects organized by trial number, scenario number, and PMs results. Scenario numbers are described in the next section.

C. DATA CODING SCHEME

Each of the eight scenarios was uniquely described by the level, high or low, of each of the three factors: Information Completeness (I), Work Load (L), and FPB C^2 (C). This information was coded as a three digit number with each digit either a '2' (high) or a

‘1’ (low). Once the data from a PM sheet was entered into Excel, the scenario from which it was generated was referred to by this three digit code (see Appendix B, columns 3, 4, and 5). For example, the scenario with I, L, and C at the high level is coded 222. The scenario with all factors at the low level is coded 111. Referencing sub-section I.A.4., we anticipated scenario 211 (high or complete information, low work load, low FPB tactical coordination) would produce the best results for Blue forces.

D. DATA REDUCTION

Initial data reduction was performed by reducing the 81 PMs which B&R was capable of producing for this experiment to the ten projected to be most relevant (see section II.E.). This was accomplished before the data collection phase. B&R automatically converts a subject’s performance to percentages, counts, and average distances and then lists them as performance measures. After the data collection phase the ten selected PMs were checked to ensure sufficient variability existed to warrant continuing with the analysis phase. Most of the PMs chosen produced good distributions.

IV. ANALYSIS

This chapter discusses the overall analysis plan and presents the results of the analysis. The information in this chapter is quite detailed and necessary for a complete understanding of the results. A summary of findings is presented in the Conclusions (Chapter V).

A. ANALYSIS PLAN

Initial data analysis utilized frequency plots to obtain a pictorial representation of the 128 data points per PM (16 subjects x 8 scenarios). This established an initial feel for the data and provided insight for further detailed analysis. The shape of some of the plots may call into question our initial assumption of normality. Next, box plots were used to examine the three factors' individual impacts on the PMs. After a working understanding of the data was obtained, three factor MANOVA was used as a screening device, and since not all PM distributions appeared normal, parametric and non-parametric ANOVA, interaction plots and residual plots were used to conduct a detailed analysis. A significance level of $\alpha = 0.05$ was used to test all null hypotheses. When the data did not appear normal, non-parametric ANOVAs were conducted over the factors suggested by MANOVA, parametric ANOVA, or the box plots.

B. RESULTS OF ANALYSIS

Detailed results of the analysis presented in this section include frequency plots and the corresponding descriptive statistics, box plots, ANOVA, two-way interaction plots, and residual plots. In addition, the results of preliminary analysis performed on the demographic information is included.

1. Frequency Plots and Descriptive Statistics (see Appendix C for plots)

BAFP 1 (FPBs detected by Blue Air (%)): Almost all FPBs were detected by Blue Air throughout the experiment. This is not surprising; Blue Forces had five helicopters to conduct Surface Search Surveillance and Coordination (SSSC).

BAFP 2 (Average range at which FPBs were first detected by Blue Air (nm.)): The average range that Blue Air first detected the FPBs was 71 nm. measured from the nearest Blue force ship.

BSP 3 (FPB's destroyed by Blue Surface (%)): Overall 75% of the FPBs were destroyed. BAFP 1 and BSP 3 plots suggest that not all FPBs were destroyed even though almost all were detected. This is probably because Blue Forces expended their limited Harpoon inventory (8 weapons per ship) or were not able to position themselves within gun range due to the time constraints of the experiment.

BSP 4 (Average range at which FPBs were destroyed by Blue Surface (nm.)): Blue Surface destroyed the FPBs at an average range of 30 nm. measured from the nearest Blue force ship (Harpoon range is 5 - 75 nm.; gun range is 1-15 nm.).

BAFP 12 (Number of TAO weapon assignments (count)): The average number of TAO weapon assignments per game was approximately 19 (i.e., the number of salvos launched by the operator per trial).

A 1 (Blue Air detected by the FPBs (%)): All Blue Air platforms were detected by the FPBs in most of the trials. Blue Air assets were required to come within the FPBs' surveillance envelopes to positively identify contacts as hostile.

S 1 (Blue Surface detected by the FPBs (%)): Overall 23.19% of Blue Surface platforms were detected by the FPBs. This is due in part to EMCON restrictions used by some FPBs.

A 2 (Average range at which Blue Air was first detected by the FPBs (nm.)): The average range that the FPBs first detected Blue Air was 45.3 nm. Measured from the nearest FPB.

S 2 (Average range at which Blue Surface was first detected by the FPBs (nm.)): The average range at that the FPBs detected Blue Surface was 17.4 nm. Measured from the nearest FPB. By combining plots S1 and S2, it is apparent that the FPBs and Blue Surface platforms operated at distances greater than their surveillance areas. The initial separation of Blue Surface and the FPBs at the start of the game was great enough so that neither

would be in the other's sensor range. This was done to force Blue to rely on the helicopters and intelligence provided to locate the FPBs.

A 3: (Blue Air destroyed by the FPBs (%)): Overall 21% of Blue Air was destroyed by the FPBs. Blue Air was susceptible to the FPBs' surface to air missiles while conducting visual identification. Electronic Surveillance Measures (ESM) information when available to Blue, may have made subjects more vigilant when operating air assets in the vicinity of unknown surface platforms. Without this information, the percentage of Blue Air destroyed could have been higher.

2. Box Plots (see Appendix D for plots)

As described earlier, the experiment examined the effects of three factors at two levels. Box plots were used to determine if there were significant differences between the distributions of the PMs for the two levels of treatment for each of the three factors. Box plots present a pictorial representation of the key features of the data: median, first and third quartiles, and spread. Significant differences in these features could indicate differences in the location or spread of the PM distribution when factor levels are altered. Within the context of these box plots, significant implies a non-trivial visual difference in the box plot with respect to the median and the first and third quartile. If differences were identified, ANOVA was conducted to gain additional insight.

Four sets of box plots were generated for each PM. The first three correspond to individual factors. The boxes labeled with a 1 represent the 64 data points corresponding to the low level of the factor, whereas those labeled with a 2 represent data for the high level of each factor. The fourth set of box plot graphics contain eight box plots representing the eight unique scenarios (each scenario's box plot contains 16 data points). It is coded in accordance with the data coding scheme described earlier. The box plots were used as a tool to help corroborate or refute the rejection of a null hypotheses and to gain insight into the nature of any effects.

3. ANOVA / Interaction and Residuals Plots (see Appendices E and F for plots)

This sub-section builds on the results of the analysis based on the frequency plots and box plots and uses the additional statistical tools described earlier to make the case for acceptance or rejection of the null hypotheses (see Appendix I) for each PM.

BAFP 1 (FPBs detected by Blue Air (%)): The Normal Plot of the ANOVA Residuals (NPR) suggests the data does not behave normally. This possibility is corroborated by the Histogram of the ANOVA Residuals Plot (HRP) and the ANOVA Residuals vs. ANOVA Fits Plot (RFP). ANOVA yields a p-value for C of 0.000. This implies that H_{03} should be rejected, however, due to the non-normality of the data we can not reject H_{03} based on ANOVA. The Kruskal-Wallis (K-W) non-parametric ANOVA, which does not require normality, was conducted and also yielded a p-value of 0.000. Based on the combined result, we reject H_{03}. It makes sense that the level of C^2 would have an impact on Blue Air's ability to detect the FPBs. The difference in means for C1 and C2 is 98.09% detected and 90.10% detected respectively. Nothing else of significance was found.

BAFP 2 (Average range at which FPBs were first detected by Blue Air (nm.)): The NPR, HRP and the RFP all indicate that the data is normal. ANOVA yields a p-value of 0.001 and 0.000 for L and C respectively. The box plots show a median value for BAFP2 that is approximately the same for L1 and L2, however, the mean value of detection is more than 3 nm. greater when the workload is low (73.02 vice 69.63nm.). For these reasons we reject H_{02}. H_{03} is also rejected, however, the operational rational is not so intuitive. The boxplots show a significant difference in both mean and median with Blue Air detecting the FPBs further out at C2 probably because there was more time between engagements to move own forces out. The p-value for the L×C interaction is 0.059. Although this is very close to the significance level, the null hypothesis for H_{04} will not be rejected. The Interaction Plots (IP) for L×C reveals little interaction. The p-value for I×L×C is 0.003. This leads us to reject H_{07}.

BSP 3 (FPB's destroyed by Blue Surface (%)): The p-values based on ANOVA suggests not rejecting any null hypotheses except of H_{03} (p-value =0.000). NPR, HRP, and the RFP all show the data to deviate from the normal. Hence, we will not base our decision on ANOVA but instead on K-W. K-W yields a p-value of 0.000 for H_{03}; on that evidence we reject H_{03}. For H_{03}, the box plots for C1 and C2 (medians = 88.89% and 66.67% respectively) indicate that fewer FPB's were killed by Blue forces when under a coordinated attack (C2). This supports our primary expectation that Blue forces will perform worse when attacked in mass by FPBs using COTS C^2. The IPs show no interactions exist for I×L, I×C, and L×C (p-values are 0.460, 0.460, 0.715, respectively)

BSP 4: (Average range at which FPBs were destroyed by Blue Surface (nm.)): NPR, HPR, and the RFP all indicate normal behavior of the data. The p-value for I (0.047) indicates H_{01} should be rejected. The descriptive statistics indicate a significant difference between the means I1 and I2 (28.5nm and 31.78nm respectively). Therefore H_{01} is rejected. We expect that with good information Blue forces will kill the enemy further out. For L and C the p-values also make the case to reject $H_{02/03}$ (0.001 and 0.002 respectively). The single factor box plot for L shows that Blue destroyed the FPBs further out when the load was light as we expect. The impact that factor C displays follows from BAFP2: since Blue Air detected the FPBs further out at C2, the FPBs destroyed were done so at a greater distance. This makes operational sense: if the enemy is detected further away then it can be destroyed at or near the outer limit of the weapon's range. For all these reasons we reject $H_{02/03}$. I×C yields a p-value of 0.011. The IP also suggests rejecting H_{05} by showing a strong interaction between I and C therefore we reject H_{05}. This synergy between I and C is most apparent when C is high and can be explained as follows: when the enemy's attack plan is organized it is easier to predict, from present positional information, future movements based on extrapolation and to detect the enemy earlier (i.e., at a greater range) than when the attack is less coordinated (more random). I×L, L×C and I×L×C all have p-values >>0.05. The IP for I×L and L×C confirms the acceptance of $H_{04/06}$ by showing little to no interaction.

BAFP 12 (Number of TAO weapon assignments (count)): NPR, HPR, and the RFP all indicate normal behavior of the data. The p-value for C is 0.000. The single factor box plot for C reveals a significant difference between the median number of TAO weapon assignments for C1 and C2 (23 and 18 count respectively). A likely reason for fewer weapon assignments being made when Blue was under a coordinated attack follows from BAFP1: since fewer FPBs were detected when Blue was under a coordinated attack, fewer could be targeted. For these reasons we reject H_{03}. No other p-values suggest rejecting a null hypothesis.

A 1 (Blue Air detected by the FPBs (%)): NPR, HPR, and the RFP all indicate non-normal behavior of the data. ANOVA yields a p-value of 0.012 for factor C. K-W yields a p-value of 0.02. The single factor box plot for C shows that the FPBs detected far fewer helicopters when they were conducting a coordinated attack (this was expected since seven of the nine FPBs were in EMCON for C2). For these reasons H_{03} is rejected. ANOVA for L×C (H_{06}) yields 0.032. The IP for L×C shows that more helicopters were detected by Red when the load for Blue was low (for both high or low C). The possible reason: when the load was low the helicopters were more accurately vectored to the FPBs. The IP for L×C also shows that when the load was high the percentage of helicopters detected by Red was about the same regardless of the level of C. For this we can find no clear operational explanation.

S 1: (Blue Surface detected by the FPBs (%)): NPR, HPR, and the RFP all indicate normal behavior of the data, however, the initial frequency plot of S 1 suggests the data may not be useful because there are only three Blue ships to detect. ANOVA yields a p-value of 0.003 for C. The single factor box plot for C registers a significant difference between C1 and C2 (medians = 33.0% and 17.0% respectively) confirming the low p-value's indication that we reject H_{03} (when C was high most of the FPBs were in EMCON). I×C p-value is 0.047. The IP also supports rejecting H_{05}, however, the full operational explanation of the interaction displayed is unclear. When C is low the percentage of Blue Surface detected by the FPB's increases when Blue has complete information (Blue closes

the distance with Red more promptly with complete information therefore Red also becomes aware of Blue's presence). When C is high the opposite occurs. Perhaps this is because there are more unintentional encounters between Blue and the FPBs when information is incomplete.

A 2: (Average range at which Blue Air was first detected by the FPBs (nm.)): NPR, HPR, and the RFP all indicate normal behavior of the data. ANOVA yields only one p-value below the cutoff: L×C = 0.000. The IP for L×C also suggests rejecting H_{06}. The operational explanation of the nature of the interaction between L×C is unclear.

S 2 (Average range at which Blue Surface was first detected by the FPBs (nm.)): During 24 of the 128 trials Blue Surface was never detected by the FPBs (this occurred seven times at C1 and 17 times at C2), unfortunately, that left the data set incomplete for this parameter. [4] The initial frequency plot and the box plots indicate that the data is not normal. The p-value for K-W with C as the factor was 0.081. The most we can say is that the mean value at which the FPBs detected Blue Surface is 17.42 nm. measured from the nearest FPB. The mean values for C1 and C2 are 17.7 and 17.08, respectively.

A 3 (Blue Air destroyed by the FPBs (%)): The initial frequency plot indicates the data is skewed to the right. The NPR and RFP also indicate that the data is non-normal. ANOVA yields a p-value of 0.002 for C. K-W for C yields 0.053; not quite small enough to reject H_{03}. The mean percentage of helicopters destroyed for C1 and C2 (15.4% and 26.9% respectively) indicates that when the FPBs conducted a coordinated attack more helicopters were destroyed. This may follow from the fact that, although we could not reject H_{03} for A2 (ANOVA p-value=0.164), the single factor box plot for C of that factor revealed a similar finding with the FPBs detecting Blue air further out when conducting a coordinated attack versus a non-coordinated attack (medians = 42 and 47nm. respectively).

---

[4] Analyzing the 24 times that Blue Surface was totally undetected using a chi-square test leads to rejecting the null hypothesis that Blue Surface is equally likely to go totally undetected for both C1 and C2 (p-value of 0.024). The estimated probabilities of Blue Surface going totally undetected are C1: 0.11 and C2: 0.27.

It also makes sense that we will lose more *scouts* when the FPBs are in an EMCON status because Blue Air must enter the FPBs weapons envelope to positively identify them. The IP for L×C reveals when the FPBs were coordinated in their attack and Blue forces work load was high, more helicopters were destroyed. We already know C has an impact, but this indicates that Blue Air assets were not managed as carefully or prudently when the work load on Blue was high.

4. Demographic Information

Of the 16 subjects, eight were USN, five were USMC, two were USAF, and one was USA. Six of the eight naval officers were surface warfare officers. Thirteen of the 16 subjects were students in the Command, Control, and Communications (C^3) curriculum at NPS. Years of service ranged from 5-16 years. A demographic questionnaire was completed by each subject during the overview brief; the questions were as follows:

1. Name
2. Rank / Branch of Service
3. Designator / MOS Description
4. Number of Years on Active Duty

Subjects were asked to rate on a scale of from one (poor) to ten (expert) their:

5. Level of Proficiency with Navy Tactical Data System (NTDS) symbology
6. Level of Proficiency with Simulation / Wargames
7. Level of Proficiency as Tactical Action Officer (TAO)
8. Level of Computer Proficiency

The answers to questions four through eight are discussed below:

- The distribution of the years of service was skewed toward more senior officers (see Appendix G, Figure 1 for details).
- The question on NTDS symbology was asked because the symbology used in B&R is very similar to NTDS symbology; it was presumed that familiarity with similar symbology would give a subject an advantage in adjusting to the

wargame. As expected, the distribution of the responses to this question were bimodal with ten of the sixteen subjects evenly split between the top end of the scale and the bottom end (see Appendix G, Figure 2 for details).

- Experience with wargames was chosen early on as a factor that could influence a subject's performance. The responses to the question regarding wargame experience appears to approach a normal distribution with responses skewed slightly toward more experience (see Appendix G, Figure 3 for details).

- Another factor that was anticipated to impact performance was proficiency as a TAO. Since a TAO qualification is specific to SWO only, we assumed that the distribution would be skewed toward the more proficient side since the participant group contained a wide range of warfare specialties. A full fifty percent of respondents claimed the lowest level on the proficiency scale (see Appendix G, Figure 4 for details).

- Finally, the data pertaining to the level of computer proficiency was evaluated. The data for this question appears to have a normal distribution skewed toward the less proficient end, with seventy five percent of the respondents claiming proficiency above the midpoint on the scale (see Appendix G, Figure 5 for details).

V. CONCLUSIONS

This chapter discusses hypotheses results and provides a summary of the most significant results. In addition, corresponding real world interpretations are offered. The previous chapter was predominantly organized by PMs. This chapter is organized by the factors and interactions (hypotheses) and focuses on significant findings. Findings are also condensed and presented in table form in Appendix H (Null Hypotheses Rejection Summary).

A. HYPOTHESES RESULTS

All three factors and three out of four of their interactions produced significant effects, although not for all PMs. All significant effects are described below.

1. Information Completeness

H_{01} had a significant impact on one PM: The average range at which the FPBs were destroyed by Blue Surface (BSP 4); $p = 0.047$, 31.8 nm. when information was complete, and 28.5 nm. when information was incomplete. With complete information Blue forces were able to kill the enemy over 3 nm. further out than with incomplete information.

2. Work Load

H_{02} had a significant impact on two PMs: The average range of detection (BAFP 2); $p = 0.001$, 69.6 nm. when Blue work load was high, and 73.0 nm. when work load was low. The average range at which the FPBs were destroyed (BSP 4); $p = 0.001$, 27.4 nm. when Blue work load was high, and 32.9 nm. when Blue work load was low. In both cases Blue's performance was adversely affected (range decreases) when work load increased.

3. FPB C^2

H_{03} had a significant impact on the following seven PMs:

- Percentage of FPBs detected by Blue Air (BAFP 1); $p = 0.000$, 90.1% detected when FPBs were coordinated, and 98.1% detected when the FPBs were not coordinated.

- Mean range of detection of the FPBs (BAFP 2); $p = 0.000$, 76 nm. when FPBs were coordinated, and 66.6 nm. when FPBs were not coordinated.

- Percentage of FPBs destroyed by Blue Surface (BSP3); $p = 0.000$, 65.5% destroyed when the FPBs were coordinated, and 84.9% destroyed when the FPBs were not coordinated.

- Mean range at which the FPBs were destroyed by Blue Surface (BSP 4); $p = 0.002$, 32.8 nm. when the FPBs were coordinated, and 27.5 nm. when the FPBs were not coordinated.

- Number of TAO weapon assignments (BAFP 12); $p = 0.000$, 17.0 assignments when the FPBs were coordinated, and 22.3 assignments when the FPBs were not coordinated.

- Percentage of Blue Air detected by the FPBs (A 1); $p = 0.012$, 93.9% detected when the FPBs were coordinated, and 97.9% detected when the FPBs were not coordinated.

- Percentage of Blue Surface detected by the FPBs (S 1); $p = 0.003$, 19.3% detected when the FPBs were coordinated, and 27.1% detected when the FPBs were not coordinated.

When the FPBs used high C^2 fewer FPBs were detected by Blue, however, of those FPBs detected the range of detection by Blue was greater. Similarly, when the FPBs had high C^2 fewer were destroyed, but those that were destroyed were done so at a greater range. It only makes sense that if they were not detected they could not be killed, and if they were detected further out, that they would be killed further out.

But why would fewer be detected and yet, those detected, be detected at greater range? The answer to this is inherent in the scenario design and is two fold. When the FPBs had high C^2, they conducted a coordinated (concurrent) attack versus an uncoordinated (sequential) attack with seven of the nine FPBs in EMCON. Without the FPBs radiating they were more difficult to detect, but due to their more structured organization Blue had more time to prepare and deploy forces.

Fewer TAO assignments were made when the FPBs used high C^2. This explains why fewer FPBs were destroyed when C^2 was high. Analyzing the operations from the

FPBs perspective reveals that the FPBs detected fewer Blue Air and Surface platforms when they used high C^2. This is a direct result and a potential disadvantage of the high C^2, EMCON tactics.

4. The Combined Effects of Information Completeness and FPB C^2

H_{05} had a significant impact on one PM: Mean range at which the FPBs were destroyed by Blue Surface (BSP 4); $p = 0.011$. When the FPBs were conducting non-coordinated attacks, information completeness had no effect. But when the FPBs used coordinated tactics, the FPBs were destroyed at a much greater range when Blue had complete information, 36.5 nm., than when Blue had incomplete information, 29.0 nm. This indicates that when Red was in EMCON, good intelligence (complete information) became more valuable.

5. The Combined Effects of Work Load and FPB C^2

H_{06} had a significant impact on one PM even though neither factor taken alone was significant for that PM.

Mean range at which Blue Air was first detected (A 2): Additional analysis does not yet help explain why the FPBs detected Blue Air further out when conducting coordinated attacks: $p = 0.000$, 46.14 nm. compared with 44.56 nm. when conducting non-coordinated attacks.

6. The Combined Effects Of Information Completeness, Work Load, and FPB C^2

H_{07} had a significant impact on one PM.

Average range of detection of the FPBs (BAFP 2): No attempt was made in this analysis to interpret this interaction.

B. SUMMARY OF MOST SIGNIFICANT HYPOTHESES RESULTS

- When Blue forces had complete information
    - FPBs were destroyed at a greater range.
- When Blue forces were under low work load

- FPBs were detected and destroyed at a greater range.

- When FPBs attacked with high C^2:

    - The number detected and destroyed decreased, and

    - The range of detection and destruction increased.

C. REAL WORLD MEANING

The fact that subjects had five helicopters scouting in a geographically constrained littoral region probably reduced the importance of judicious resource allocation and thus lessened the effect of information completeness. In essence, the subjects had nearly total radar coverage provided by the helicopters regardless of where they directed them.

FPB C^2 levels caused changes in more PMs than any other factor. Probable causes include:

- FPBs were in EMCON when C^2 was high which greatly affected their ability to *see* and be *seen.*

- When FPB C^2 was high their tactics differed greatly than when their C^2 was low. In the former case, the FPBs converged on Blue in three concentric waves, thereby massing forces for saturation attacks. In the latter case, the attack was more sequential and random. The net result might be that even though Blue was able to conduct a more methodical and deliberate counterattack when the FPBs had high C^2 they could not detect as many and therefore could not kill as many.

VI. RECOMMENDATIONS

This chapter proposes ways in which to improve and extend the experiment.

A. CHANGES TO THE EXPERIMENT

The experiment could be improved by more realistically modeling information completeness and work load. Reducing the number of helicopters would help determine if information completeness is modeled correctly. Fewer resources would force the operator to allocate them more judiciously. Work load could be varied between high and low based on real world maximum and minimum shipping levels in the scenario's geographic area to ensure applicability to present day operations. The FPB threat is an emerging one so it will be more difficult to find real world data on which to model FPB C^2 and tactics but this aspect of the study should be pursued.

Due to time and human resources constraints a limited pilot study was conducted (seven different subjects, three trials each). A larger pilot study would help ensure the factors are modeled more accurately and the PMs (dependent variables) are capturing the dynamic range of the performance curve.

A more homogeneous group of subjects (preferably surface warfare officers) would help to further reduce the impact of the learning effect and ensure that all of the subjects were starting with the same baseline knowledge of naval tactics.

Configuring the software to automatically store and transfer each subjects' trial data would have expedited the data collection process and would have protected against transposition errors in the data.

B. CONTINUATION OF THE EXPERIMENT

The easiest way to extend this analysis is to segregate subjects by warfare specialty, service, or other demographic factor and then analyze the data accordingly. For instance, this would help determine if the changes in the levels of information were not registered in more PMs because of inaccurate modeling, or a cancellation effect due to certain subjects

utilizing the scripted message information prudently and others acting regardless of message content. Other ways include: replicating the experiment on another simulation system to show the affects of B&R artifacts, using different scenarios to neutralize scenario effects, or investigating different factors or different levels of studied factors.

APPENDIX A. PM DATA COLLECTION SHEET

CC4103 EXPERIMENT #1 05 -16 FEB 96

Name: [illegible]

Scenario: PG 14

Trial: 4

Parameters	**BAFP BA vs RS Results**	**BSP BS vs RS Results**	**BASP BAS vs RS Results**
1. Surface threats detected	[illegible] %	0.00 %	77.[illegible] %
2. Ave Range at which threats were first detected	69.00 nm	NaN nm	69.00 nm
3. Surface threats destroyed	0.00 %	44.44 %	[illegible] %
4. Ave Range at which threats were destroyed	NaN nm	18.25 nm	18.85 nm
5. Surface threats missiles detected	58.33 %	41.67 %	100.00 %
6. Ave Range at which cruise missiles first detected	22.71 nm	15.28 nm	19.55 nm
7. Surface threats cruise missiles destroyed	0.00 %	0.00 %	0.00 %
8. Average range at which cruise missile destroyed	NaN nm	NaN nm	NaN nm
9. Surface threat cruise missile heads up call	58.35 %	41.67 %	100.00 %
10. Real time taken to set up defenses	1.98 min	1.98 min	1.98 min
11. Real time from beginning to end of scenario	35.23 min	35.23 min	35.23 min
12. Number of TAO weapons assignments	10	10	10
13. Real ave time for TAO weapon assignments	5.56 sec	5.60 sec	6.66 sec
14. Real ave time between TAO weapon assignments	NaN sec	NaN sec	NaN sec
15. Perceived confidence level (0-9)	4	4	4

Parameters	**RSP RS vs BA Results**	**RSP RS vs BS Results**	**RSP RS vs BAS Results**
1. Blue force air platforms detected	100.00 %	16.67 %	54.55 %
2. Average range at which platforms were first detected	45.25 nm	24.00 nm	41.67 nm
3. Blue force air platforms destroyed	50.00 %	0.00 %	36.36 %
4. Average range at which platforms were destroyed	5.50 nm	NaN nm	5.50 nm
5. Blue force air missile detected	NaN %	100.00 %	100.00 %
6. Average range at which cruise missiles were detected	NaN nm	10.33 nm	[illegible] nm
7. Blue force air cruise missiles destroyed	NaN %	8.33 %	8.33 %
8. Average range at which cruise missiles were destroyed	NaN nm	0.00 nm	0.00 nm
9. Targets (HVU) destroyed by surface platforms	0.00 %	0.00 %	0.00 %
10. Red force surface platforms destroyed	0.00 %	44.44 %	44.44 %
11. Average range at which red platforms destroyed	NaN nm	18.25 nm	18.25 nm
12. Real time from beginning to end of scenario	35.23 min	35.23 min	35.23 min

Figure 1. PM Data Collection Sheet

APPENDIX B. EXCEL WORKSHEET

Name	Trial	I	L	C	BAFP1	BAFP2	BSP3	BSP4	BAFP12	A1	S1	A2	S2	A3
Sub 1	1	1	2	1	100.00	57.89	66.67	20.83	26	80	16.67	58.50	16.00	0
	2	2	1	1	100.00	60.67	66.67	15.17	30	100	50.00	41.80	20.00	0
	3	1	1	2	100.00	79.33	55.56	18.80	16	100	33.33	47.60	21.00	0
	4	1	2	2	77.78	69.00	44.44	18.25	10	100	16.67	45.28	24.00	80
	5	1	1	1	100.00	57.33	77.78	15.86	20	100	33.33	40.40	17.50	0
	6	2	2	1	88.89	61.62	66.67	15.83	21	100	50.00	50.00	16.67	0
	7	2	1	2	100.00	66.78	44.44	18.50	18	80	50.00	47.25	19.67	0
	8	2	2	2	100.00	59.78	66.67	19.67	19	80	33.33	44.00	21.00	0
Sub 2	1	2	2	2	100.00	80.56	66.67	38.17	19	100	0.00	46.00	N	20
	2	1	2	2	77.78	79.57	88.89	25.75	20	100	33.33	38.40	17.00	100
	3	2	1	1	100.00	66.56	88.89	32.12	26	100	33.33	49.80	19.50	20
	4	2	1	2	100.00	82.78	88.89	54.62	19	100	0.00	48.40	N	40
	5	2	2	1	100.00	67.33	88.89	29.25	32		16.67	60.00	14.00	20
	6	1	2	1	100.00	70.56	100.00	32.00	25	100	33.33	40.00	19.50	20
	7	1	1	2	100.00	89.56	66.67	25.67	38	100	50.00	49.60	16.33	40
	8	1	1	1	100.00	69.22	100.00	34.89	27	100	16.67	31.00	14.00	20
Sub 3	1	2	2	2	88.89	76.25	77.78	40.00	12	100	0.00	44.40	N	0
	2	2	1	1	100.00	70.56	88.89	37.75	13	100	0.00	49.00	N	0
	3	1	2	2	66.67	69.33	55.56	31.60	12	100	16.67	44.40	24.00	60
	4	1	1	2	100.00	79.67	66.67	38.57	18	100	0.00	58.20	N	20
	5	2	2	1	100.00	63.67	88.89	19.62	22	100	33.33	49.00	20.00	20
	6	1	1	1	100.00	62.00	88.89	25.62	26	100	33.33	38.60	19.50	0
	7	2	1	2	88.89	76.62	88.89	31.12	21	100	33.33	42.40	20.00	20
	8	1	2	1	100.00	60.00	100.00	19.44	28	100	33.33	49.00	17.50	20
Sub 4	1	1	1	1	100.00	64.56	88.89	39.12	16	100	0.00	41.00	N	0
	2	1	2	2	77.78	67.57	33.33	35.67	7	100	0.00	37.00	N	80
	3	2	1	2	88.89	81.75	77.78	56.29	9	100	0.00	50.00	N	0
	4	2	1	1	100.00	72.65	88.89	32.38	15	100	16.67	30.60	17.00	20
	5	1	2	1	100.00	74.67	77.78	26.71	21	100	33.33	40.00	17.00	20
	6	2	2	1	100.00	71.11	88.89	27.62	22	100	33.33	42.60	20.00	20
	7	1	1	2	100.00	94.44	77.78	53.29	10	100	0.00	50.40	N	40
	8	2	2	2	100.00	77.56	77.78	46.57	9	100	0.00	26.40	N	0
Sub 5	1	2	2	1	100.00	56.44	77.78	22.86	16	100	16.67	53.00	17.00	20
	2	2	1	2	100.00	70.56	77.78	37.00	23	100	0.00	39.00	N	0
	3	1	1	2	100.00	68.33	66.67	21.67	17	80	16.67	45.00	18.00	0
	4	1	2	2	88.89	63.00	55.56	15.60	22	100	33.30	40.20	17.00	80
	5	2	2	2	100.00	78.11	55.56	28.68	16	100	16.67	41.00	14.00	40
	6	1	2	1	88.89	63.62	77.78	28.57	12	100	16.67	39.40	14.00	20
	7	2	1	1	77.78	68.43	77.78	28.57	13	100	16.67	39.80	14.00	60
	8	1	1	1	100.00	71.78	100.00	46.11	17	100	0.00	40.00	N	20

Figure 2. Worksheet, Subjects 1-5

Name	Trial	I	L	C	BAFP1	BAFP2	BSP3	BSP4	BAFP12	A1	S1	A2	S2	A3
Sub 6	1	2	2	1	100.00	64.89	77.78	26.86	35	80	33.33	48.75	16.50	20
	2	1	1	2	44.44	78.75	22.22	18.50	25	80	16.67	48.25	14.00	0
	3	2	1	2	44.44	75.75	22.22	30.00	28	60	33.33	58.67	15.50	0
	4	2	1	1	88.89	71.62	77.78	26.29	31	100	16.67	49.60	15.00	0
	5	2	2	2	55.56	74.80	22.72	19.00	22	100	16.67	49.60	14.00	0
	6	1	1	1	88.89	65.38	77.78	26.29	26	100	16.67	42.40	14.00	20
	7	1	2	2	77.78	79.14	33.33	24.67	25	80	16.67	54.75	15.00	0
	8	1	2	1	100.00	69.11	77.78	22.43	29	100	16.67	48.80	15.00	0
Sub 7	1	1	1	2	88.89	76.00	77.78	17.57	18	100	33.33	45.00	17.50	40
	2	2	2	1	100.00	69.56	88.89	23.38	15	100	33.33	41.60	15.00	20
	3	1	2	1	100.00	67.11	88.89	21.50	19	100	50.00	47.60	18.33	20
	4	1	1	1	100.00	67.89	88.89	17.62	30	100	33.33	41.20	14.50	0
	5	1	2	2	88.89	73.38	55.56	12.60	18	100	33.33	30.80	19.00	20
	6	2	1	1	100.00	69.44	88.89	22.28	29	100	33.33	39.60	17.00	0
	7	2	2	2	100.00	78.22	77.78	25.00	18	80	16.67	44.25	19.00	40
	8	2	1	2	100.00	81.67	77.78	42.00	17	60	16.67	59.67	14.00	0
Sub 8	1	2	1	2	77.78	67.14	33.33	56.33	20	60	0.00	40.67	N	0
	2	2	2	1	100.00	64.33	77.78	13.29	34	80	50.00	41.25	16.33	0
	3	1	1	1	100.00	61.89	88.89	24.38	27	80	33.33	56.50	17.50	0
	4	1	2	1	100.00	57.00	77.78	17.14	43	80	33.33	57.50	21.00	0
	5	2	1	1	100.00	68.89	100.00	26.44	24	100	33.33	39.80	20.50	20
	6	1	2	2	100.00	72.67	66.67	28.50	19	100	33.33	45.60	14.00	40
	7	2	2	2	100.00	67.78	88.89	24.88	19	100	16.67	46.80	14.00	20
	8	1	1	2	100.00	75.67	77.78	34.57	11	80	16.67	56.50	14.00	20
Sub 9	1	1	2	2	44.44	70.75	33.33	22.67	10	80	16.67	46.75	20.00	60
	2	1	1	1	100.00	66.44	88.89	39.38	13	100	16.67	41.40	20.00	40
	3	2	2	2	100.00	74.56	66.67	47.33	13	100	0.00	42.20	N	40
	4	2	2	1	100.00	74.11	88.89	42.62	14	100	0.00	46.80	N	40
	5	1	1	2	100.00	90.78	66.67	42.00	17	100	16.67	50.00	25.00	20
	6	2	1	1	100.00	70.33	100.00	34.00	16	100	50.00	30.40	20.00	20
	7	1	2	1	100.00	72.67	100.00	38.89	11	80	0.00	47.75	N	40
	8	2	1	2	100.00	82.67	77.78	45.86	6	100	16.67	47.60	14.00	20
Sub 10	1	1	1	2	77.78	75.71	44.44	32.25	21	100	0.00	46.80	N	20
	2	1	2	1	100.00	68.78	77.78	42.00	0	100	16.67	56.00	15.00	0
	3	2	2	1	100.00	67.56	88.89	24.62	27	100	50.00	55.60	19.00	20
	4	2	2	2	100.00	81.11	77.78	48.14	10	80	16.67	42.75	15.00	40
	5	1	2	2	100.00	67.44	66.67	25.17	23	80	33.33	32.25	17.50	80
	6	2	1	2	100.00	82.44	100.00	50.22	18	80	16.67	45.00	14.00	0
	7	1	1	1	100.00	71.67	88.89	34.88	27	100	33.33	33.60	20.00	20
	8	2	1	1	100.00	71.78	100.00	41.33	12	100	0.00	39.60	N	0

Figure 3. Worksheet, Subjects 6-10

Name	Trial	I	L	C	BAFP1	BAFP2	BSP3	BSP4	BAFP12	A1	S1	A2	S2	A3
Sub 11	1	2	1	1	100.00	71.67	66.67	26.67	27	100	16.67	60.00	14.00	20
	2	2	2	2	100.00	77.56	44.44	27.50	19	100	16.67	46.00	18.00	0
	3	1	2	1	100.00	70.78	77.78	28.00	23	100	33.33	42.20	16.00	0
	4	1	1	1	100.00	69.00	100.00	23.67	23	100	16.67	40.60	20.00	20
	5	2	1	2	88.89	83.00	77.78	33.00	13	100	16.67	55.30	14.00	0
	6	1	1	2	88.89	80.75	88.89	30.38	11	100	0.00	57.20	N	20
	7	2	2	1	100.00	65.00	88.89	22.50	25	100	16.67	34.40	20.00	20
	8	1	2	2	100.00	75.56	66.67	24.17	23	100	33.33	47.00	14.50	80
Sub 12	1	2	1	1	100.00	61.11	77.78	25.57	29	100	33.33	45.40	17.50	80
	2	1	2	1	100.00	73.00	77.78	24.29	21	100	33.33	47.40	17.00	40
	3	2	2	2	100.00	82.56	66.67	39.00	16	100	33.33	50.00	15.50	60
	4	2	2	1	100.00	62.67	88.89	30.00	23	100	16.67	50.20	15.00	40
	5	2	1	2	100.00	81.67	66.67	44.33	23	100	16.67	48.40	19.00	20
	6	1	2	2	88.89	71.25	66.67	29.83	23	100	16.67	40.60	15.00	80
	7	1	1	1	100.00	68.33	88.89	22.00	36	100	50.00	40.00	20.00	20
	8	1	1	2	100.00	69.78	100.00	32.67	21	100	33.33	48.20	14.00	0
Sub 13	1	1	2	2	88.89	71.00	66.67	23.83	17	100	33.33	47.40	17.00	80
	2	2	2	2	100.00	78.22	66.67	44.50	15	100	0.00	53.28	N	20
	3	1	1	1	100.00	68.22	88.89	32.25	18	100	16.67	33.60	20.00	0
	4	1	2	1	100.00	69.56	88.89	19.62	22	100	50.00	40.20	18.33	40
	5	1	1	2	100.00	89.67	77.78	42.14	10	100	16.67	43.00	14.00	40
	6	2	1	2	100.00	77.44	77.78	31.14	17	100	33.33	47.00	17.00	0
	7	2	2	1	100.00	56.25	88.89	20.25	20	100	50.00	42.20	20.33	60
	8	2	1	1	100.00	71.11	88.89	21.75	25	100	33.33	40.40	17.58	0
Sub 14	1	1	1	1	100.00	64.44	77.78	22.00	26	100	33.33	39.60	19.50	0
	2	2	1	2	100.00	75.78	77.78	39.43	14	100	16.67	48.20	14.00	0
	3	1	2	2	77.78	72.00	77.78	25.43	15	100	33.33	39.80	17.00	80
	4	1	1	2	100.00	77.78	88.89	30.88	19	100	16.67	49.40	15.00	20
	5	1	2	1	100.00	67.11	88.89	22.88	23	100	33.33	38.60	17.00	0
	6	2	2	2	88.89	76.62	77.78	37.00	12	100	0.00	46.60	N	40
	7	2	1	1	100.00	71.11	100.00	41.44	11	100	16.67	49.40	19.00	20
	8	2	2	1	88.89	60.75	88.89	20.62	28	100	50.00	41.00	20.00	40
Sub 15	1	1	2	1	100.00	58.33	55.56	26.20	8	80	33.33	46.25	16.50	0
	2	1	1	2	66.67	70.67	11.11	32.00	1	80	0.00	50.00	N	0
	3	2	1	1	100.00	64.56	77.78	22.71	22	100	50.00	43.80	16.33	0
	4	2	1	2	100.00	70.78	66.67	19.83	18	100	50.00	56.00	20.00	0
	5	1	1	1	100.00	61.33	66.67	26.50	14	100	16.67	44.80	18.00	20
	6	2	2	2	100.00	75.11	55.56	15.60	18	100	33.33	48.20	16.50	0
	7	1	2	2	88.89	71.25	55.56	17.40	15	100	50.00	45.80	18.33	40
	8	2	2	1	88.89	61.62	77.78	21.14	20	100	33.33	39.40	14.50	0

Figure 4. Worksheet, Subjects 11-15

Name	Trial	I	L	C	BAFP1	BAFP2	BSP3	BSP4	BAFP12	A1	S1	A2	S2	A3
Sub 16	1	2	1	2	44.44	72.75	44.44	39.00	21	80	0.00	35.50	N	20
	2	1	1	1	88.89	67.75	77.78	41.00	21	100	0.00	47.40	N	0
	3	2	2	1	77.78	69.43	66.67	25.67	27	100	33.33	55.20	19.50	20
	4	2	2	2	88.89	64.00	77.78	38.29	18	100	16.67	39.00	19.00	20
	5	2	1	1	100.00	69.44	100.00	45.44	19	100	16.67	48.00	19.00	0
	6	1	1	2	100.00	89.44	100.00	52.67	21	100	16.67	47.40	15.00	0
	7	1	2	1	100.00	71.78	88.89	34.12	23	100	16.67	50.20	20.00	20
	8	1	2	2	100.00	72.56	66.67	43.00	17	80	50.00	46.25	19.67	20

Figure 5. Worksheet, Subject 16

APPENDIX C. FREQUENCY PLOTS

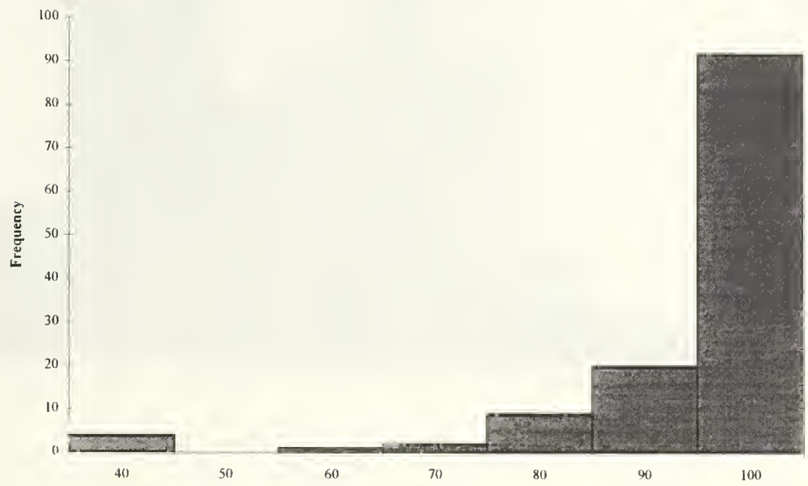

Figure 6. Frequency Plot for BAFP 1

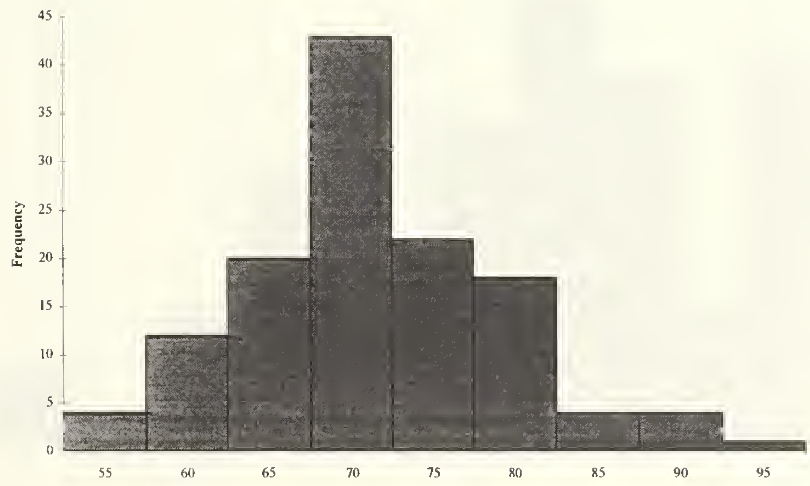

Figure 7. Frequency Plot for BAFP 2

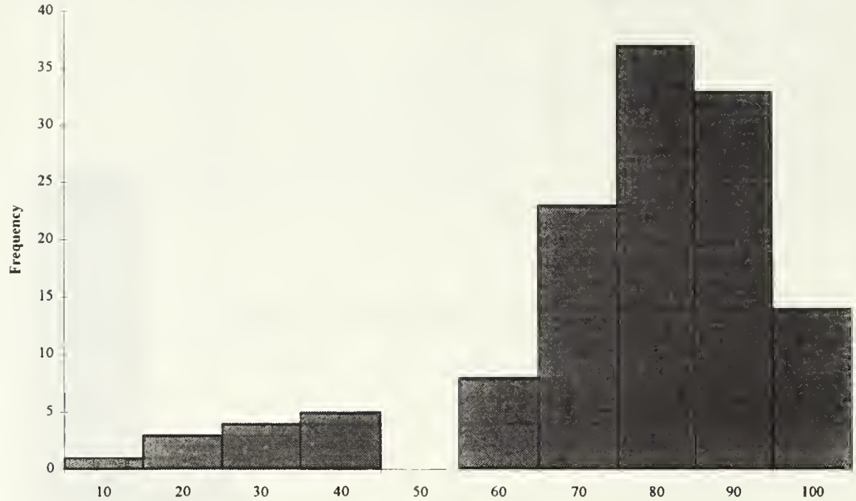

Figure 8. Frequency Plot for BSP 3

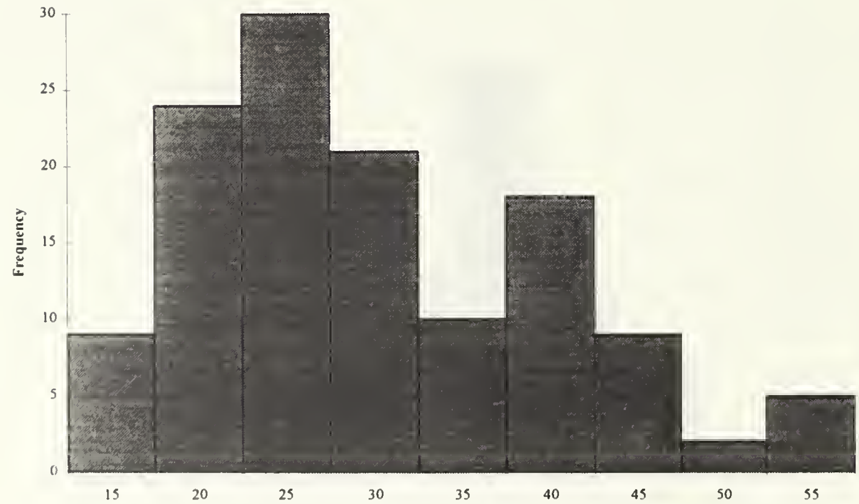

Figure 9. Frequency Plot for BSP 4

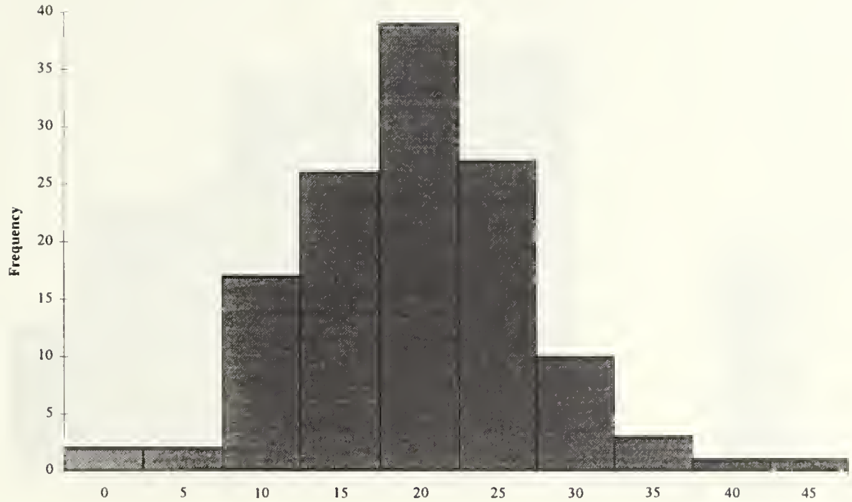

Figure 10. Frequency Plot for BAFP 12

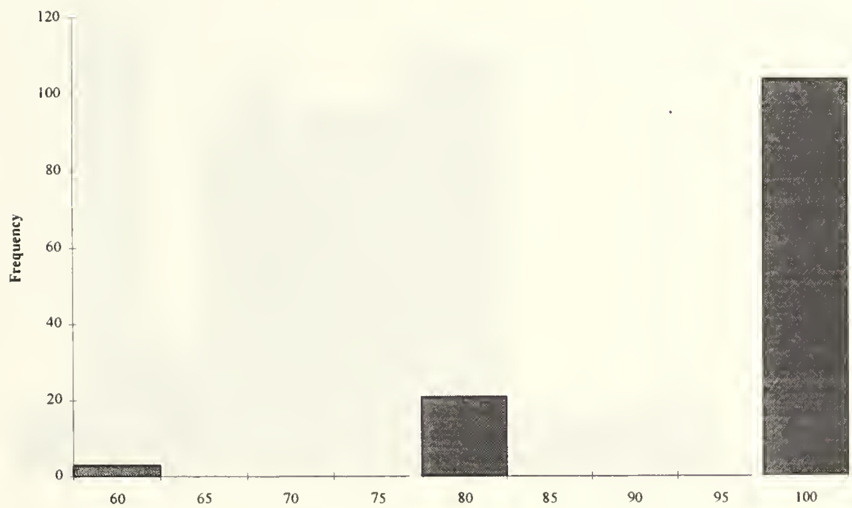

Figure 11. Frequency Plot for A1

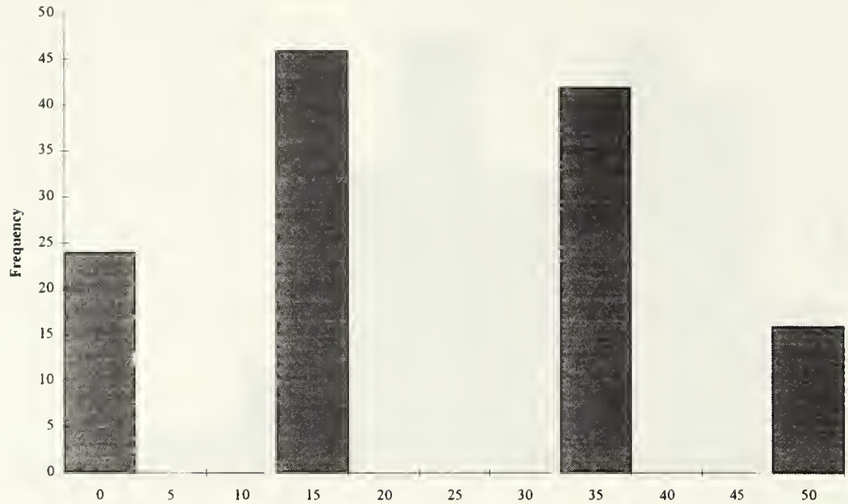

Figure 12. Frequency Plot for S1

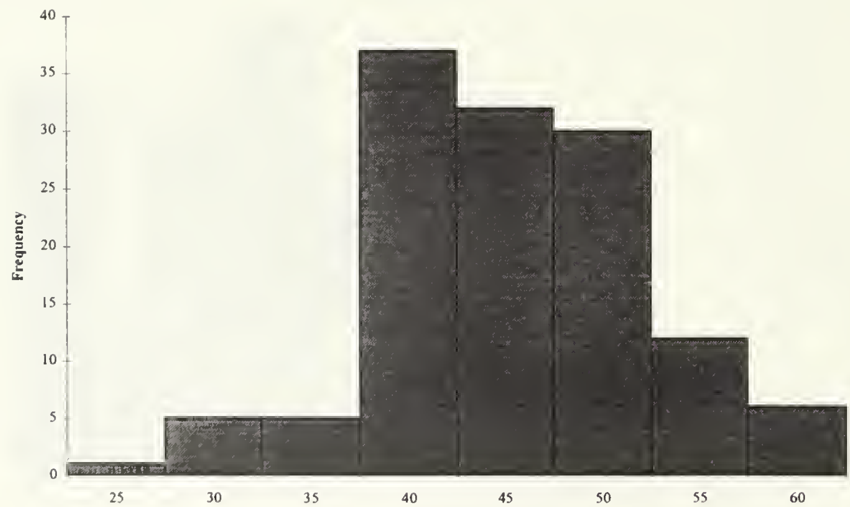

Figure 13. Frequency Plot for A2

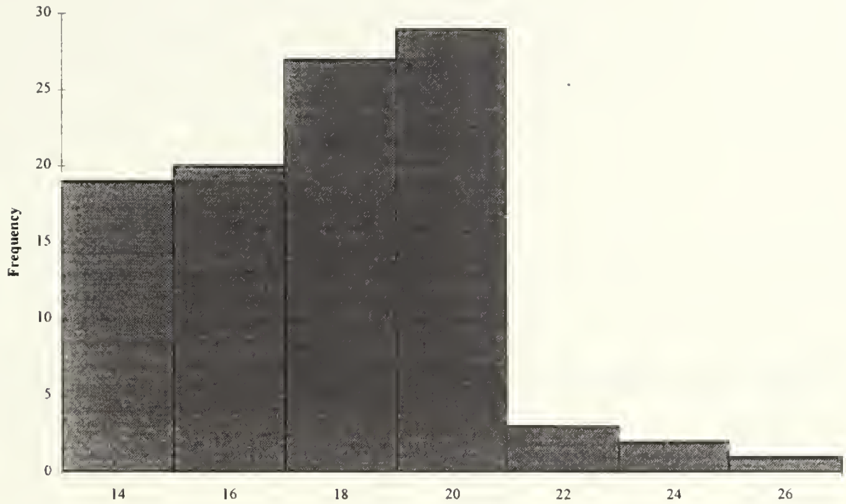

Figure 14. Frequency Plot for S2

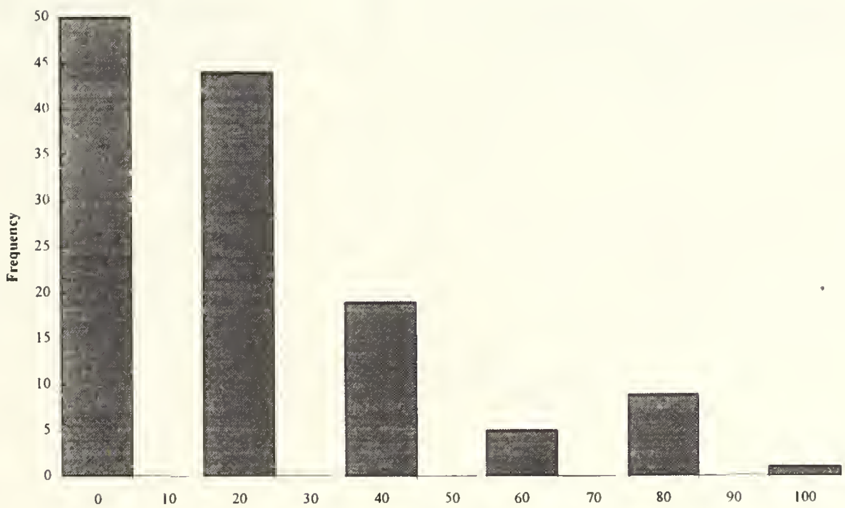

Figure 15. Frequency Plot for A3

APPENDIX D. BOX PLOTS

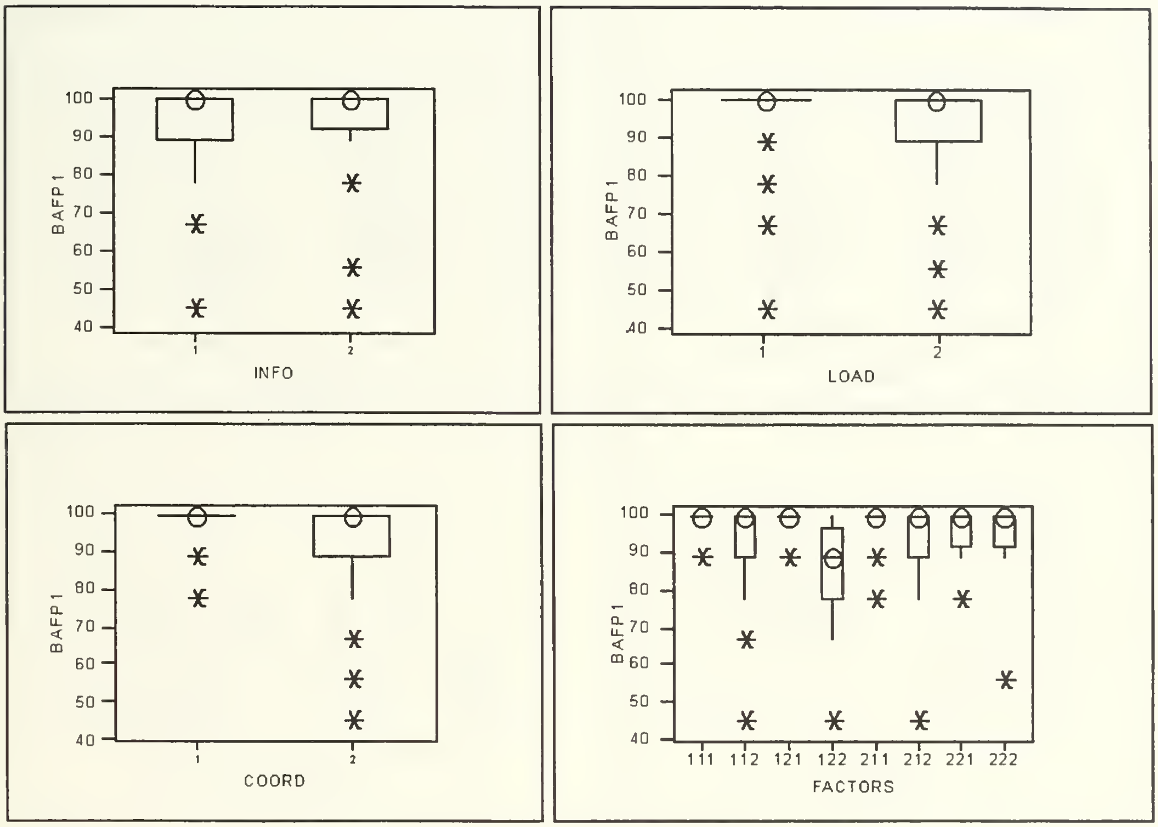

Figure 16. BAFP 1 Box Plots

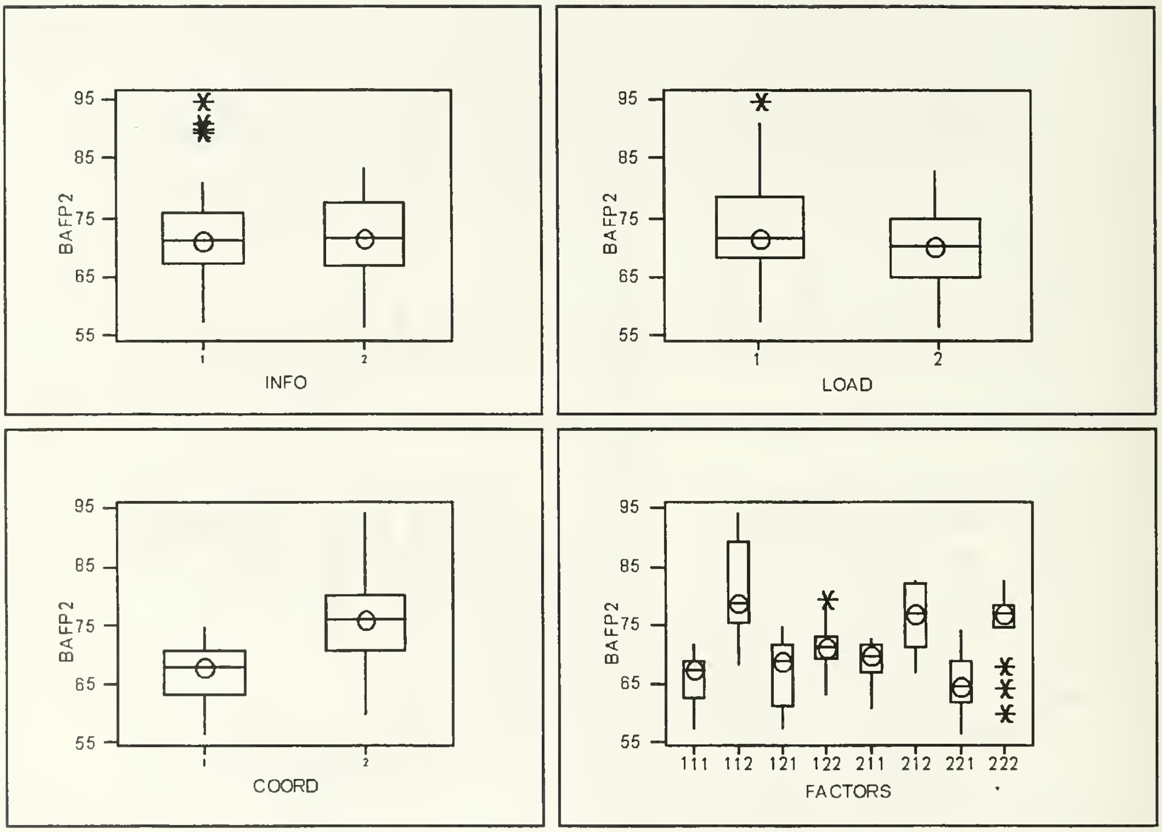

Figure 17. BAFP 2 Box Plots

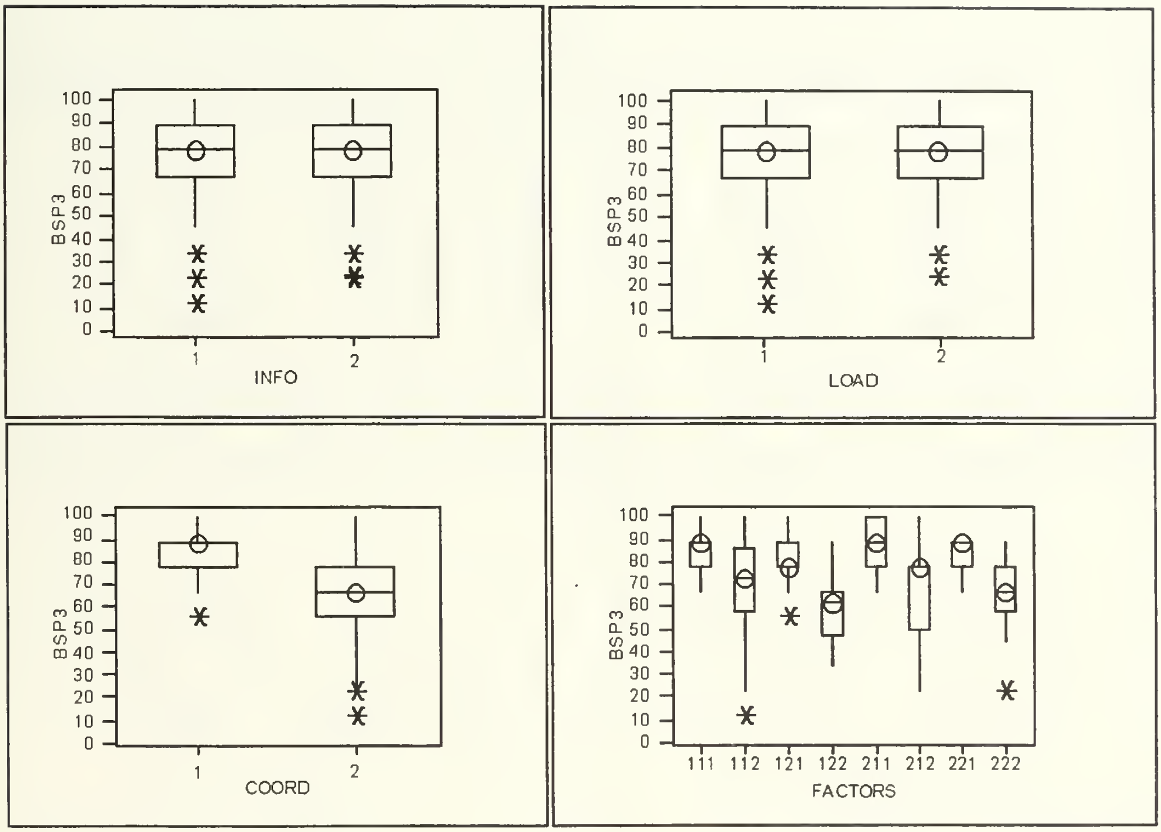

Figure 18. BSP 3 Box Plots

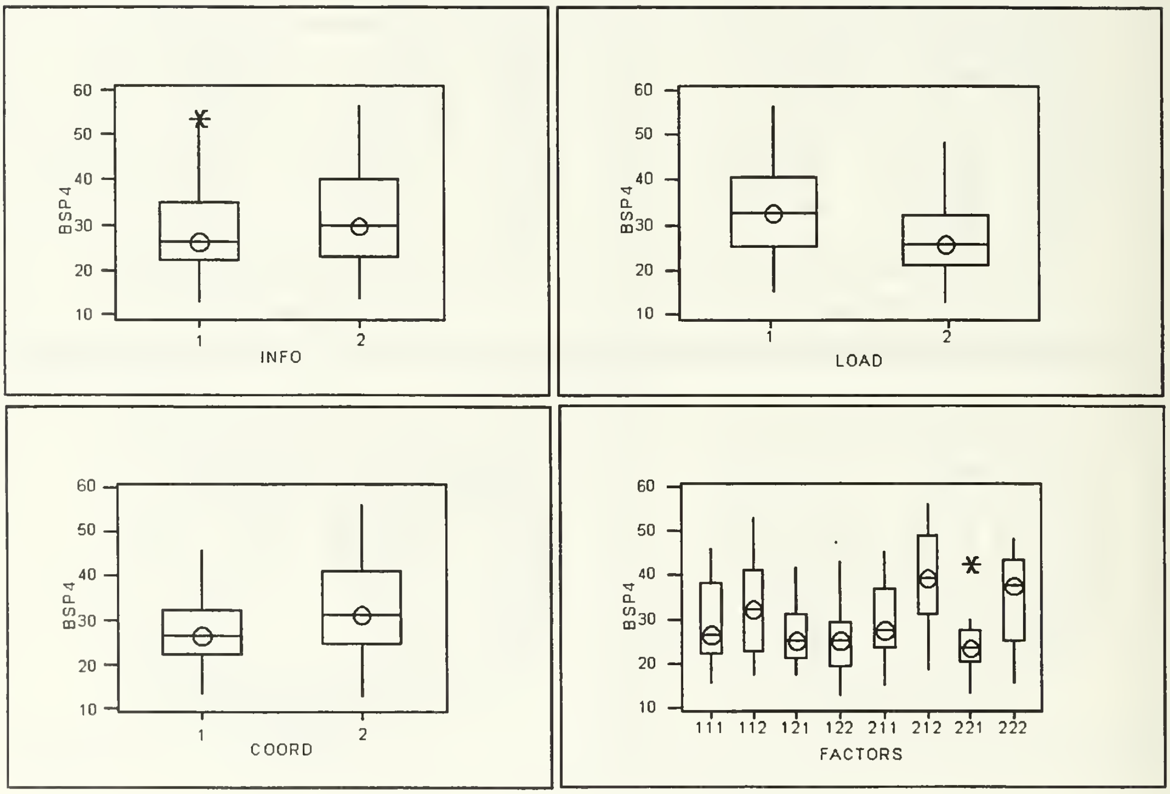

Figure 19. BSP 4 Box Plots

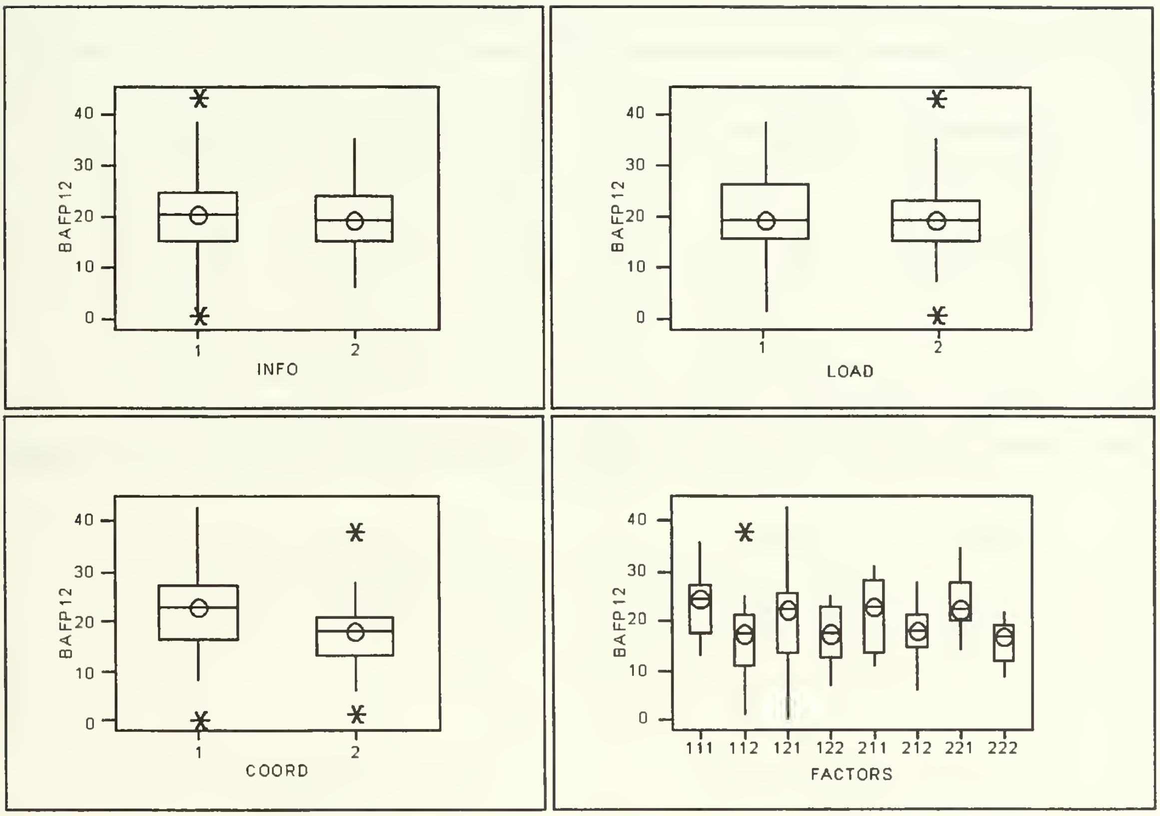

Figure 20. BAFP 12 Box Plots

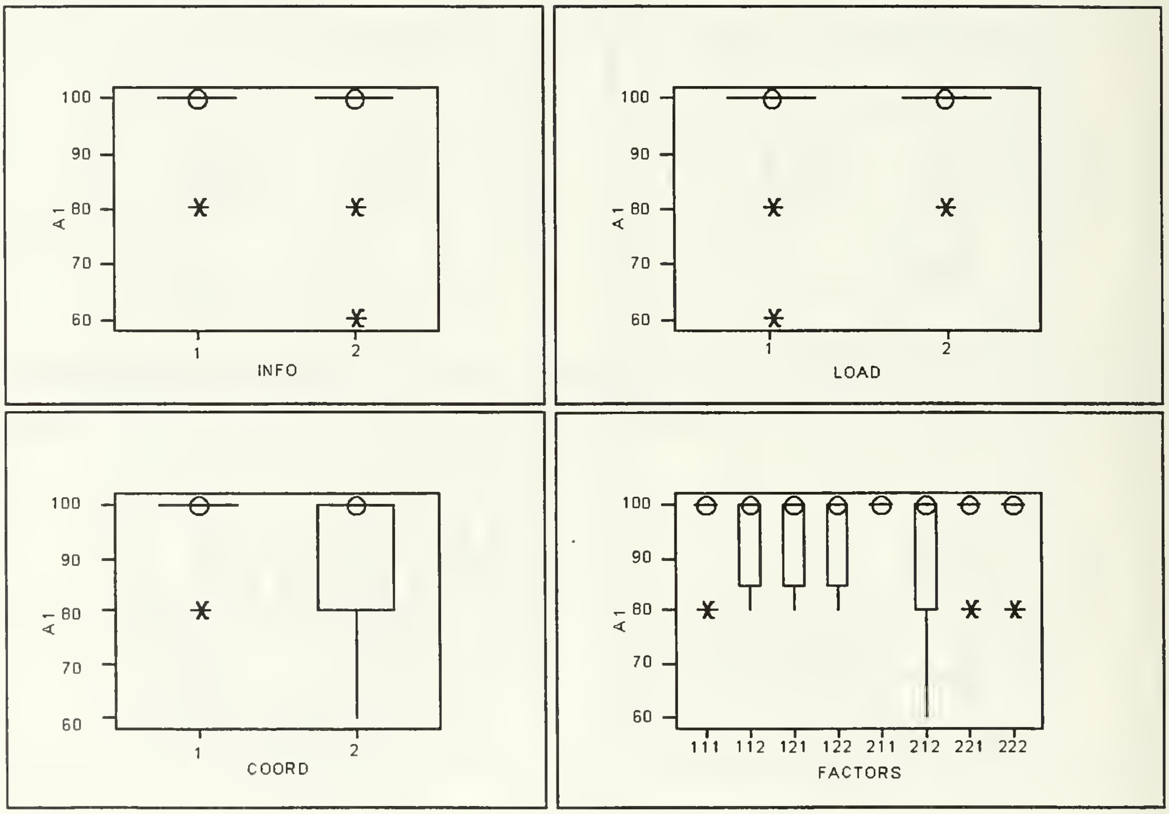

Figure 21. A 1 Box Plots

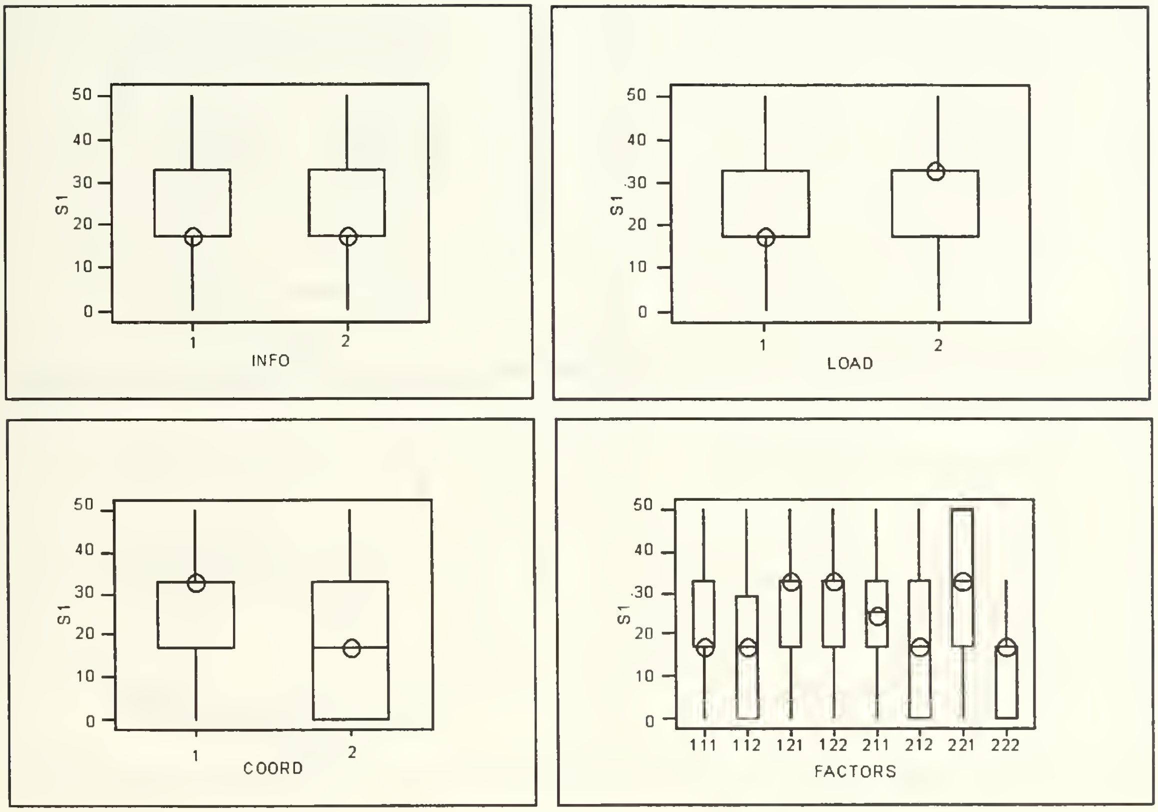

Figure 22. S 1 Box Plots

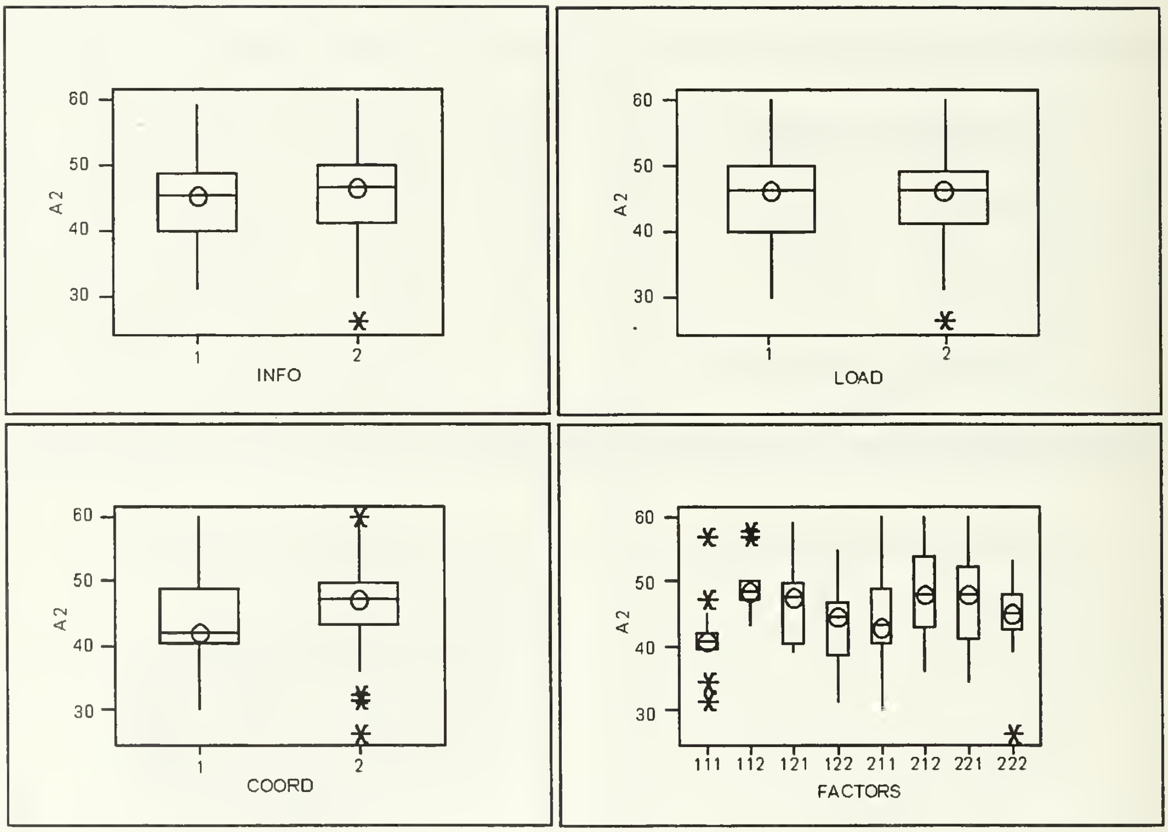

Figure 23. A 2 Box Plots

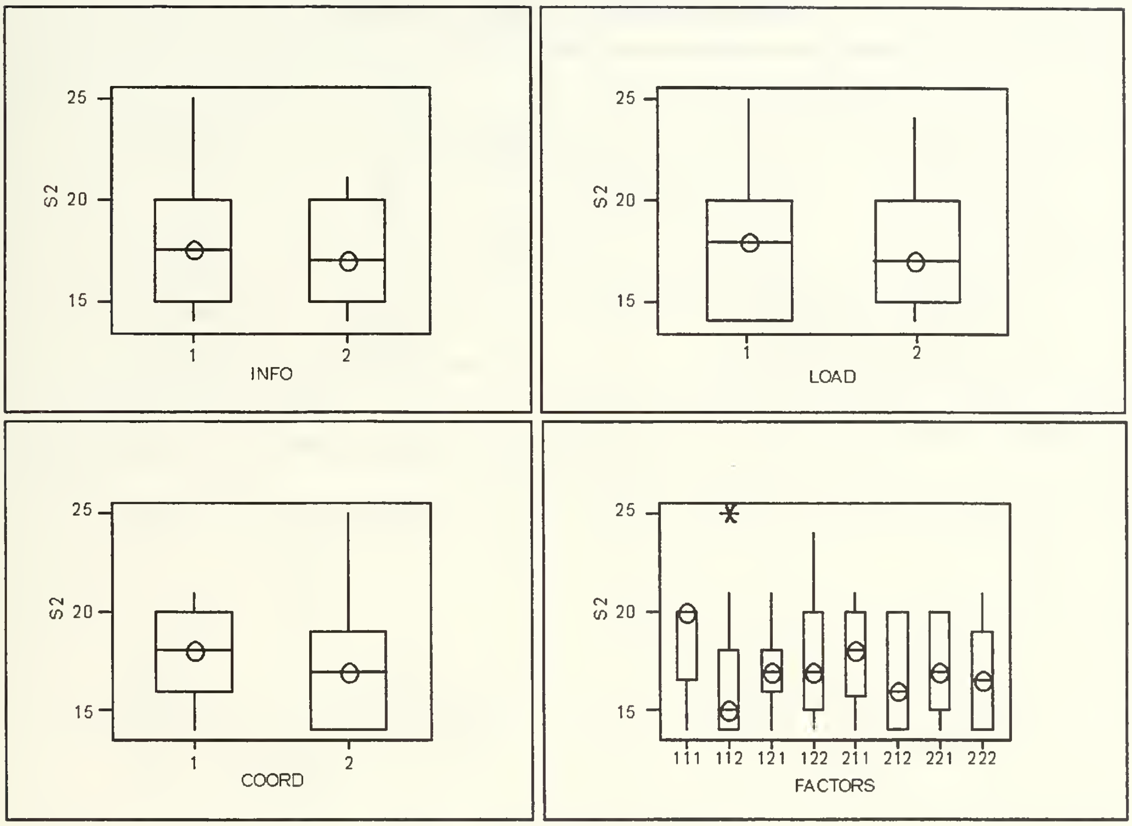

Figure 24. S 2 Box Plots

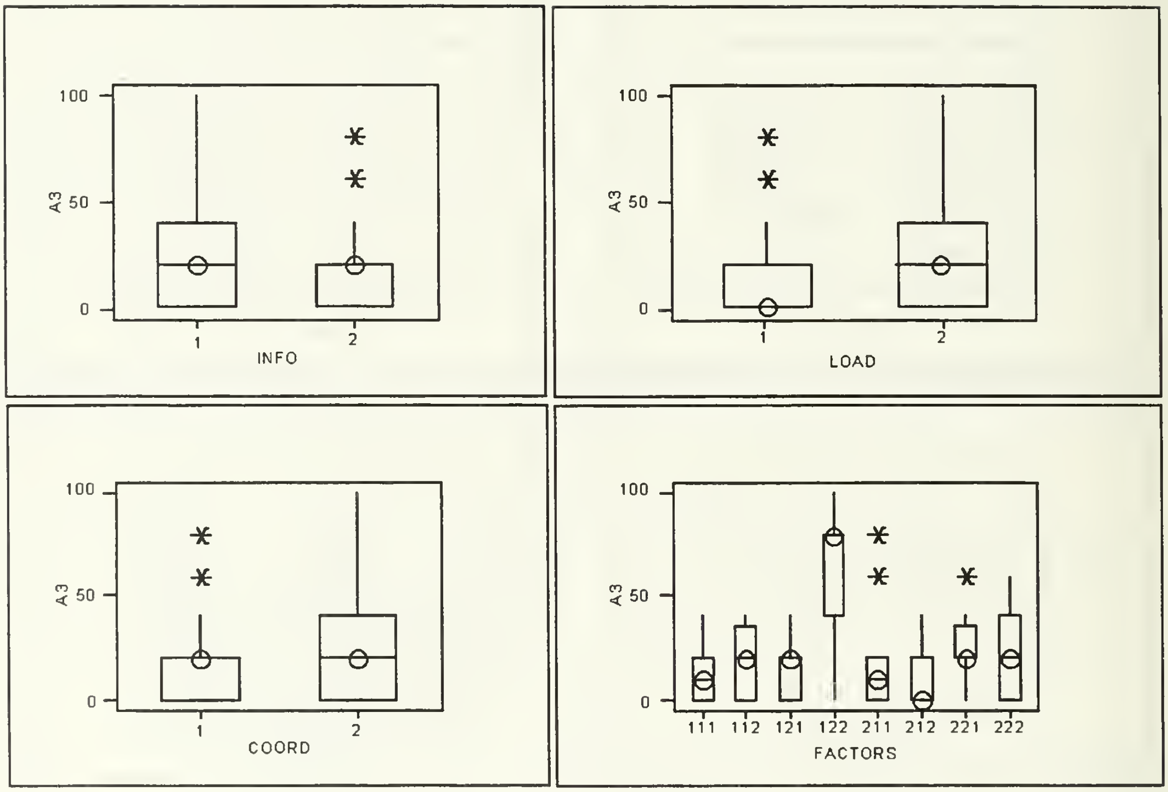

Figure 25. A3 Box Plots

APPENDIX E. INTERACTION PLOTS

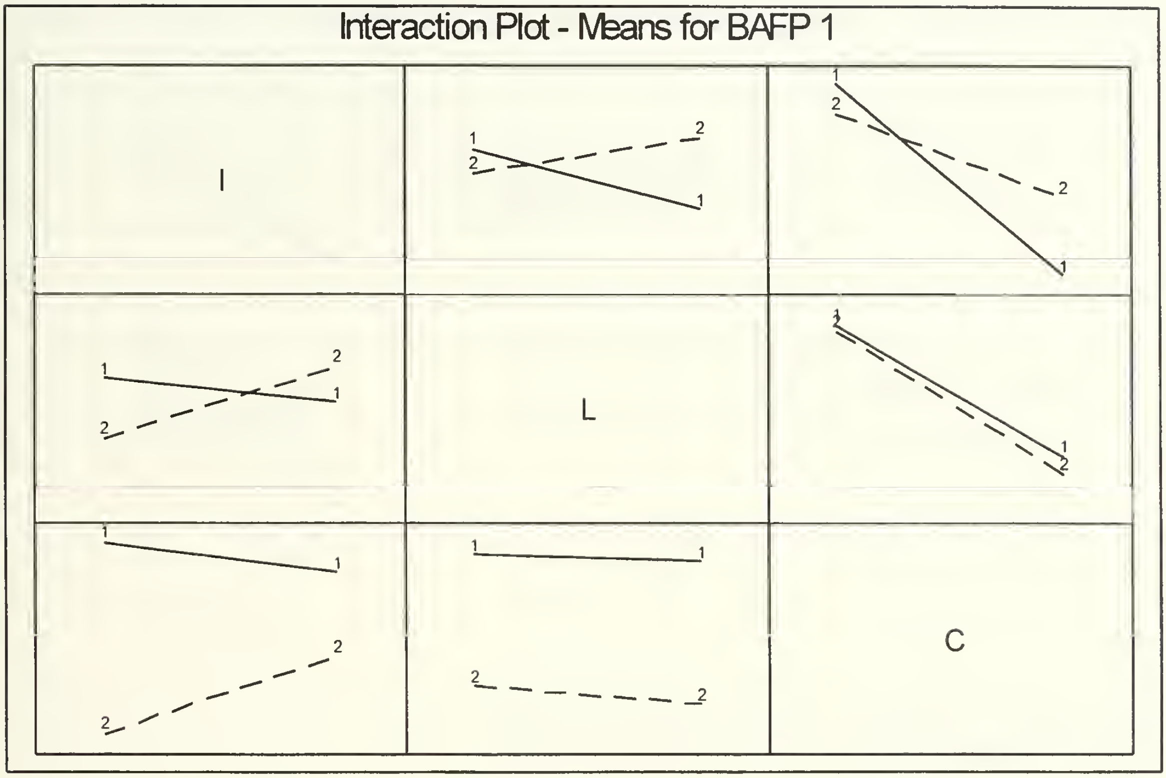

Figure 26. BAFP 1 Interaction Plots

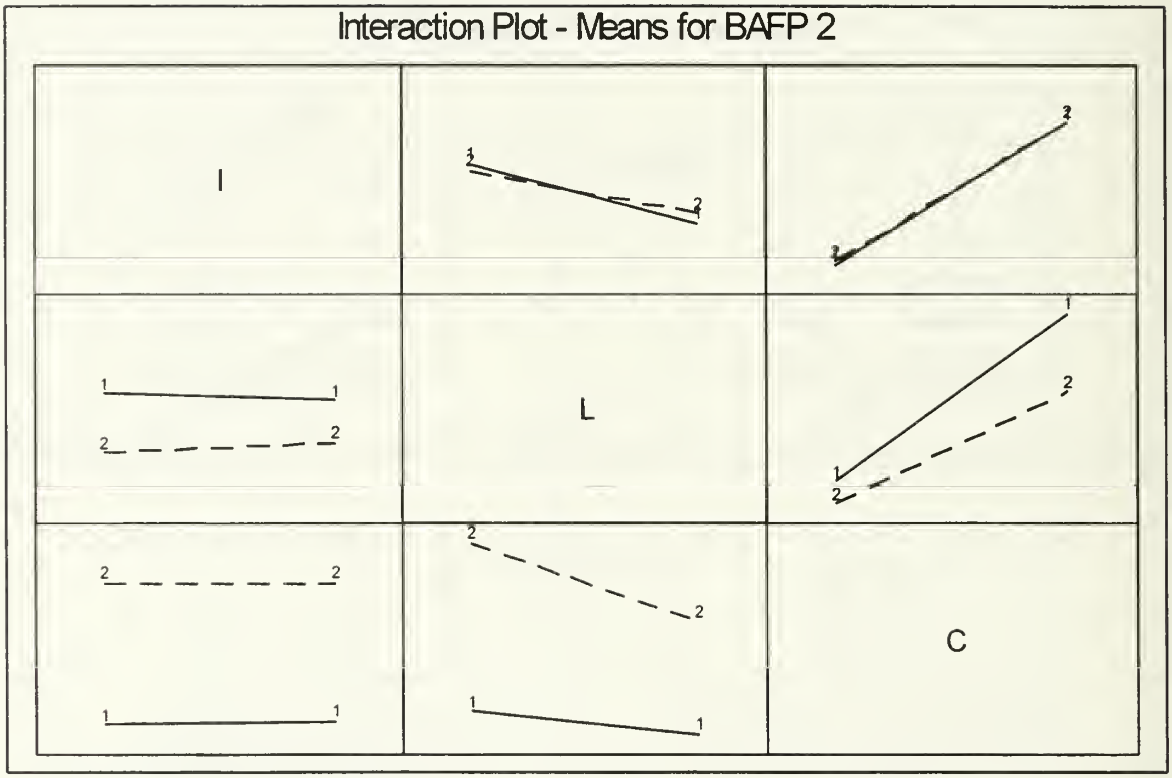

Figure 27. BAFP 2 Interaction Plots

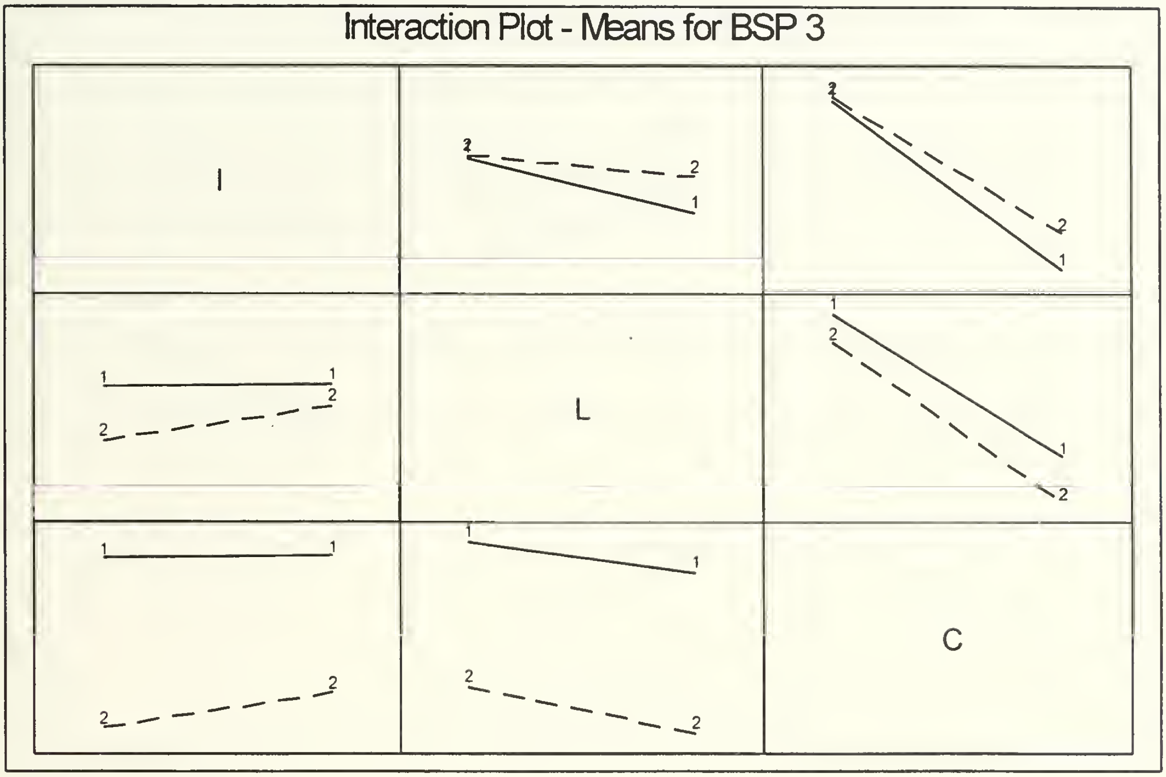

Figure 28. BSP 3 Interaction Plots

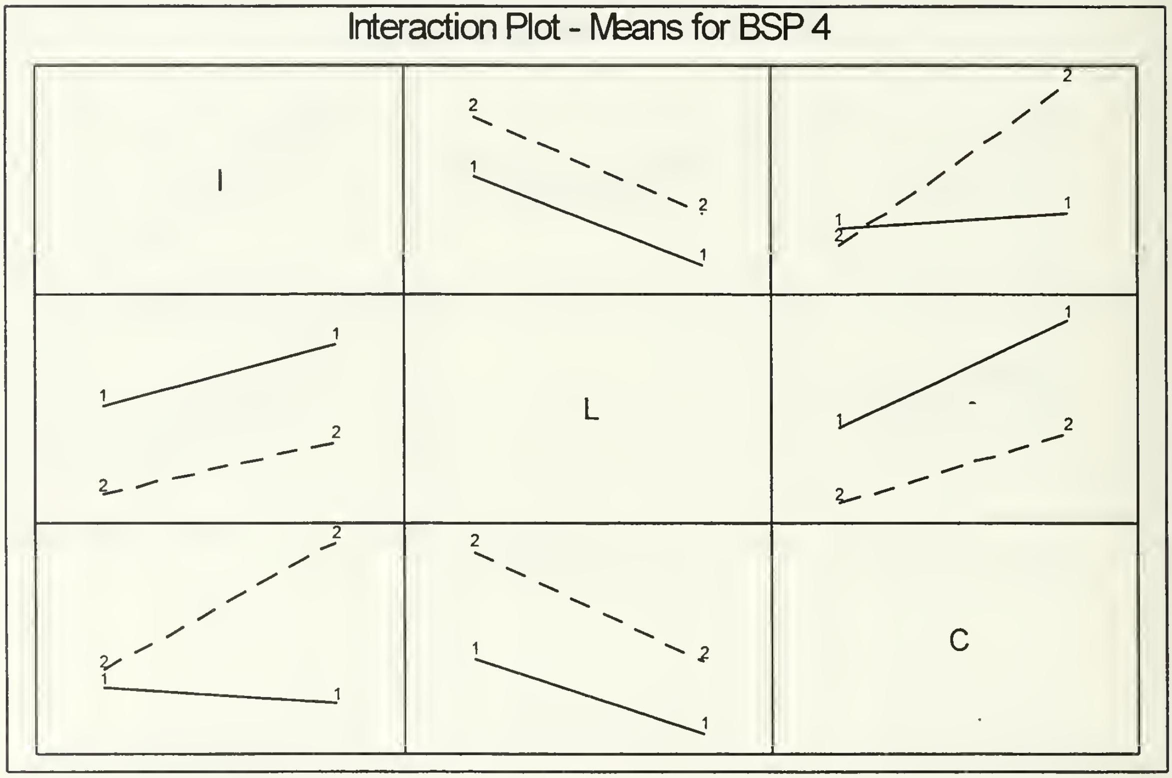

Figure 29. BSP 4 Interaction Plots

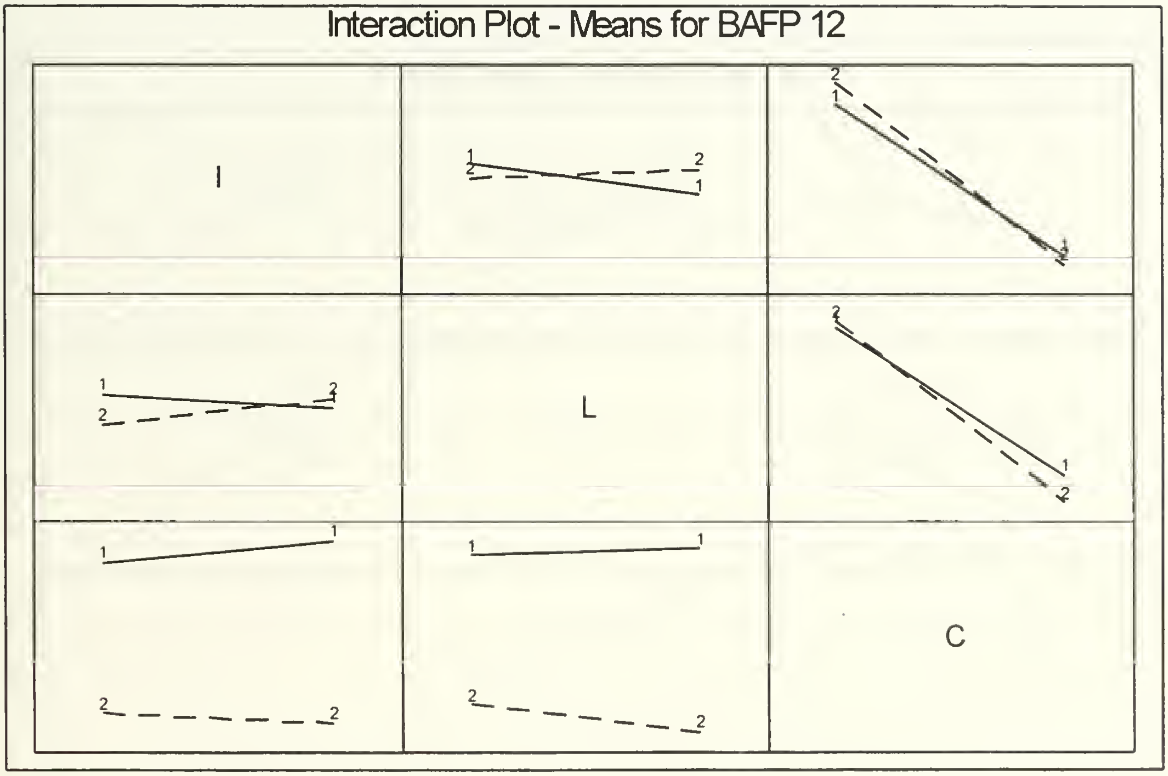

Figure 30. BAFP 12 Interaction Plots

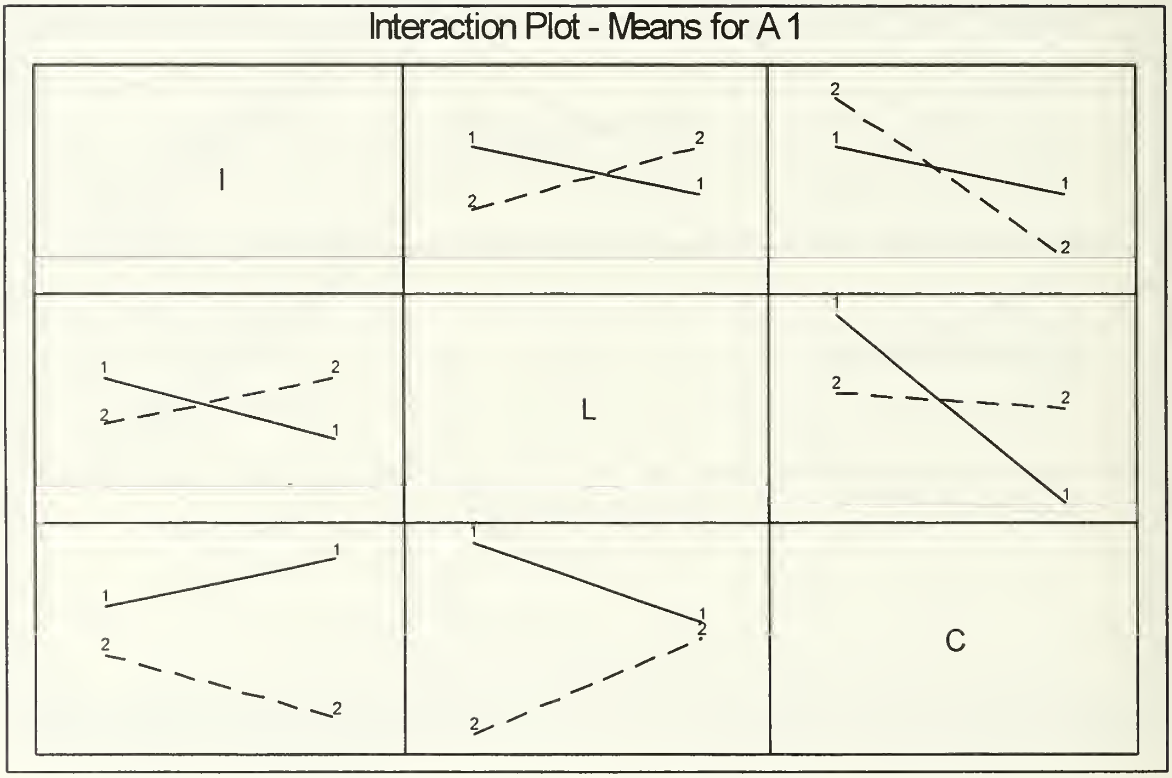

Figure 31. A 1 Interaction Plots

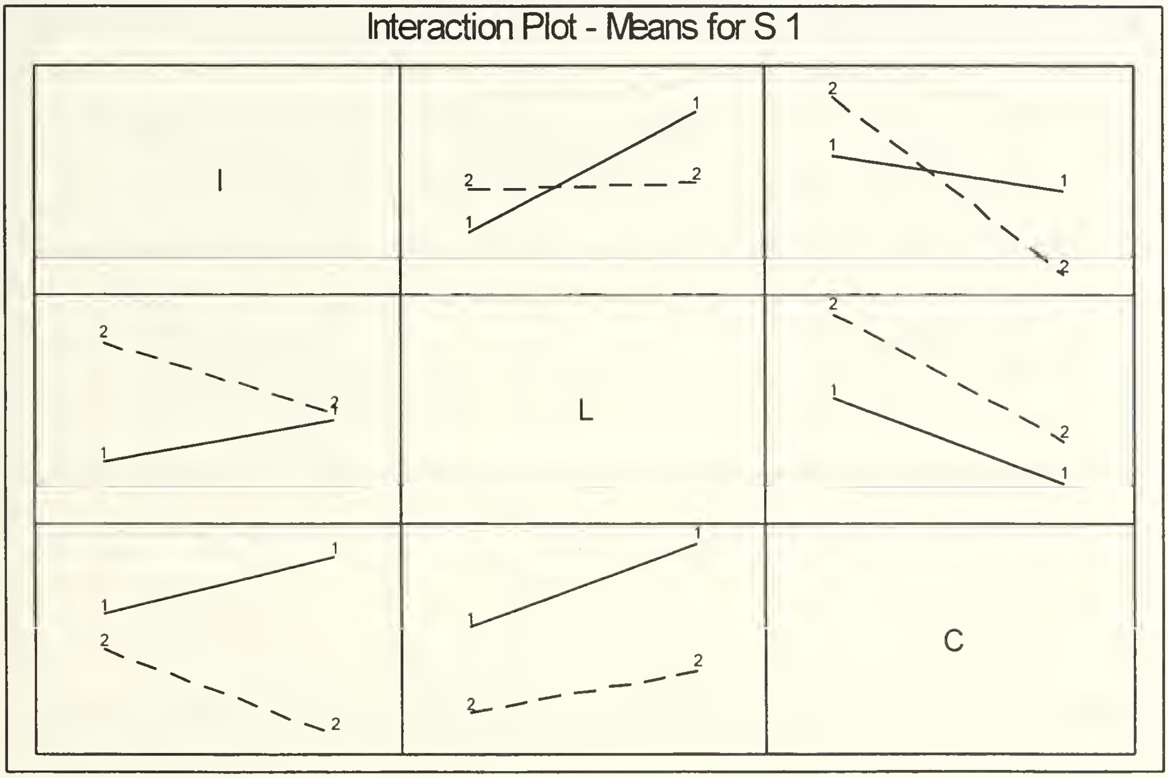

Figure 32. S 1 Interaction Plots

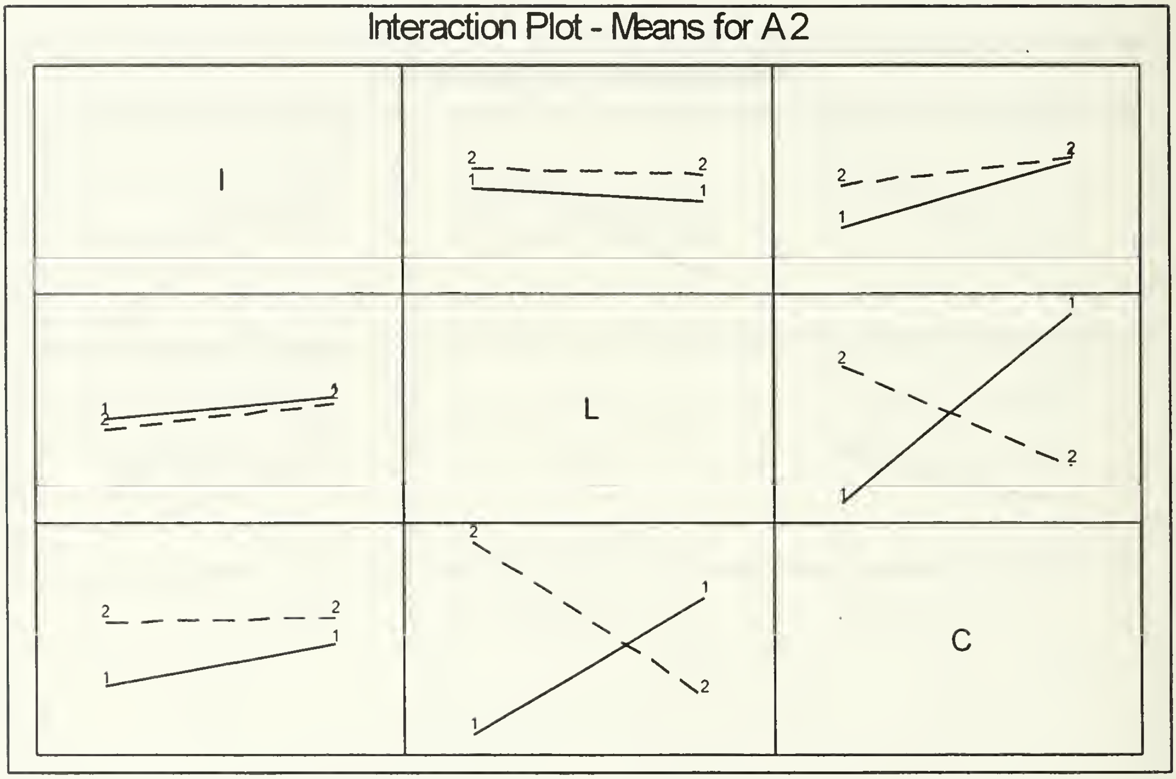

Figure 33. A 2 Interaction Plots

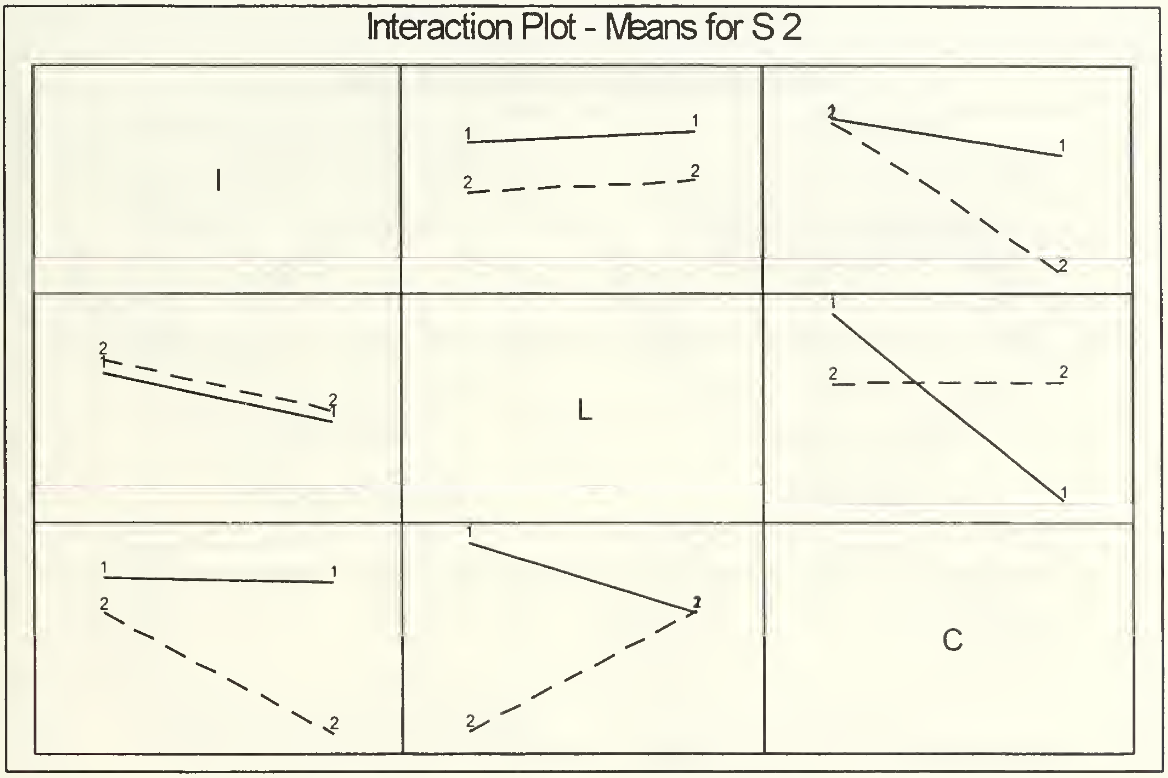

Figure 34. S 2 Interaction Plots

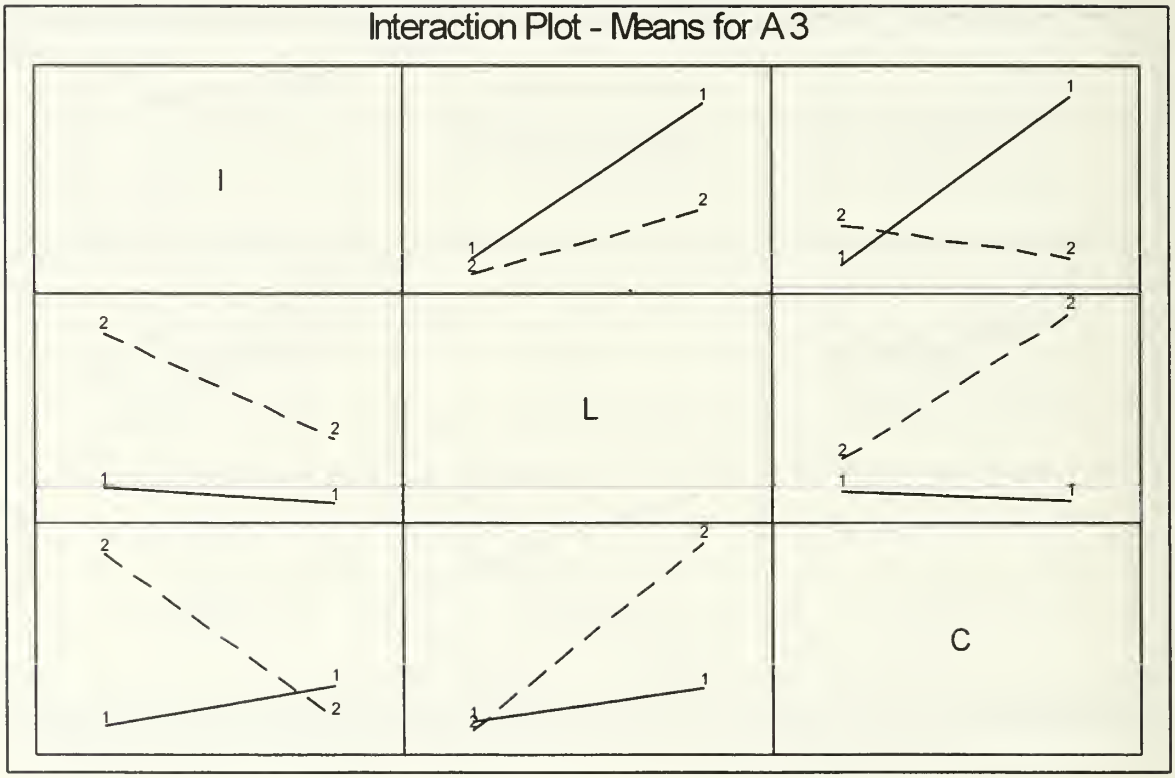

Figure 35. A3 Interaction Plots

APPENDIX F. RESIDUALS PLOTS

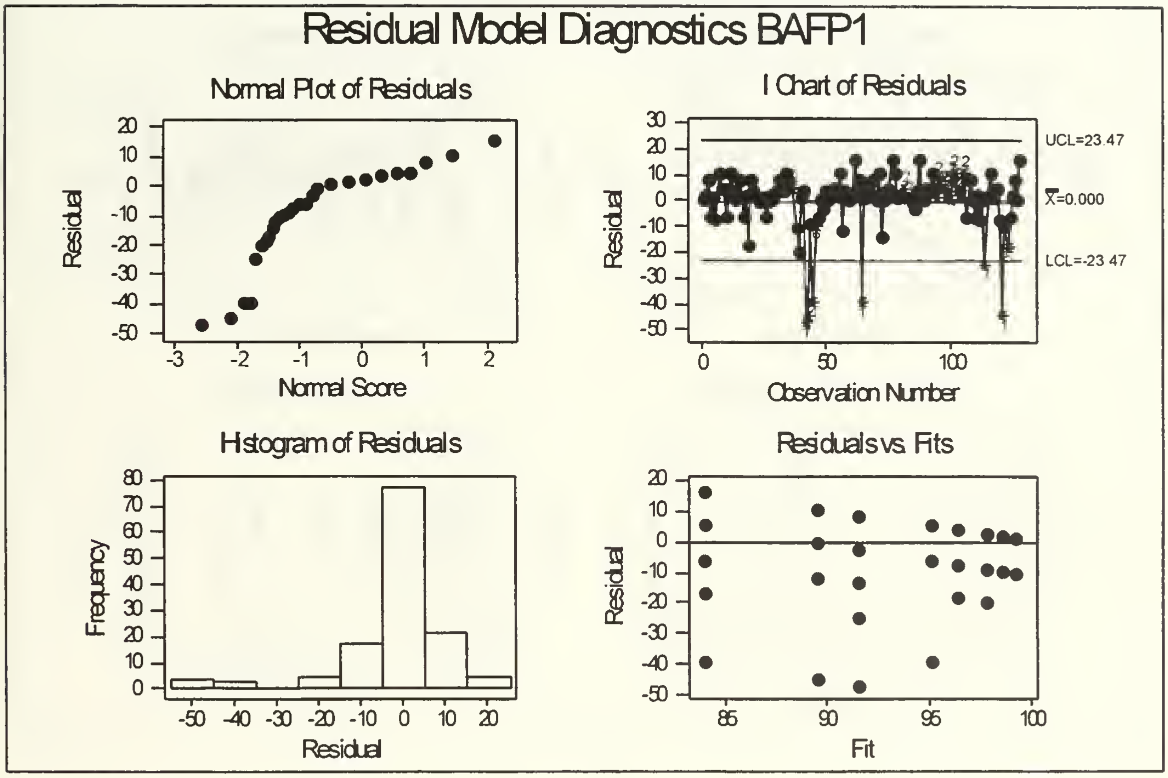

Figure 36. BAFP 1 Residuals Plots

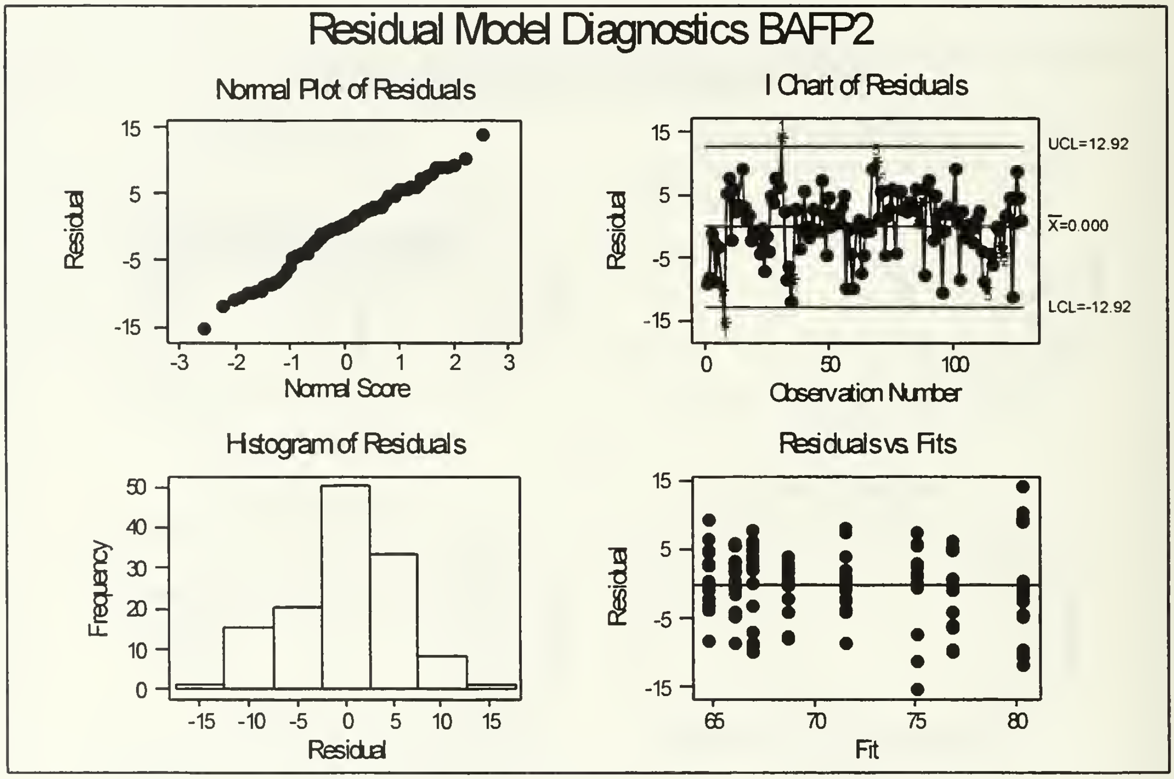

Figure 37. BAFP 2 Residuals Plots

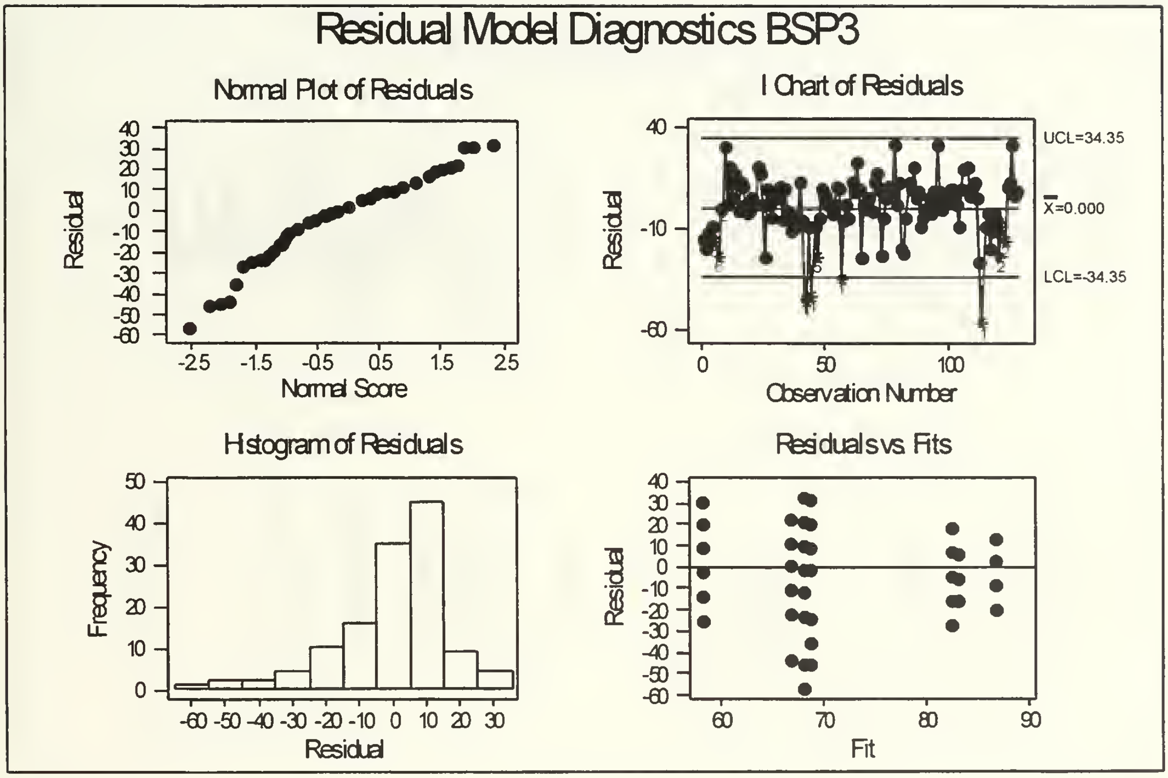

Figure 38. BSP 3 Residuals Plots

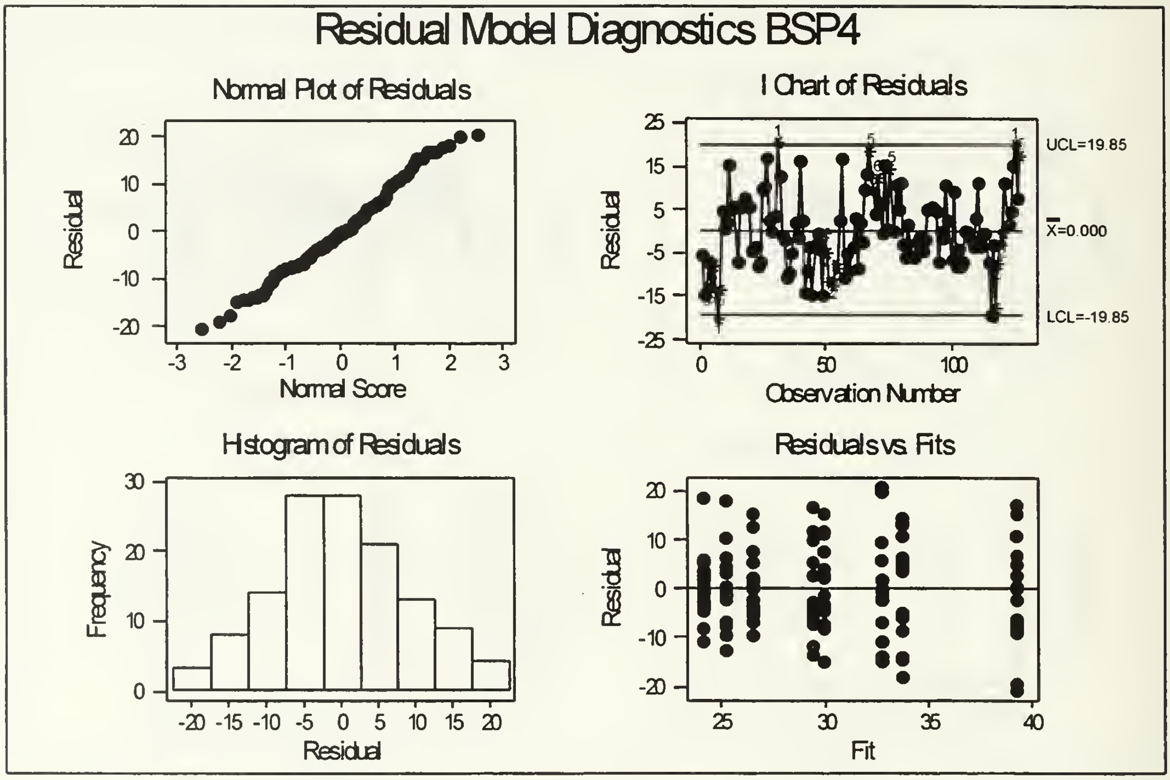

Figure 39. BSP 4 Residuals Plots

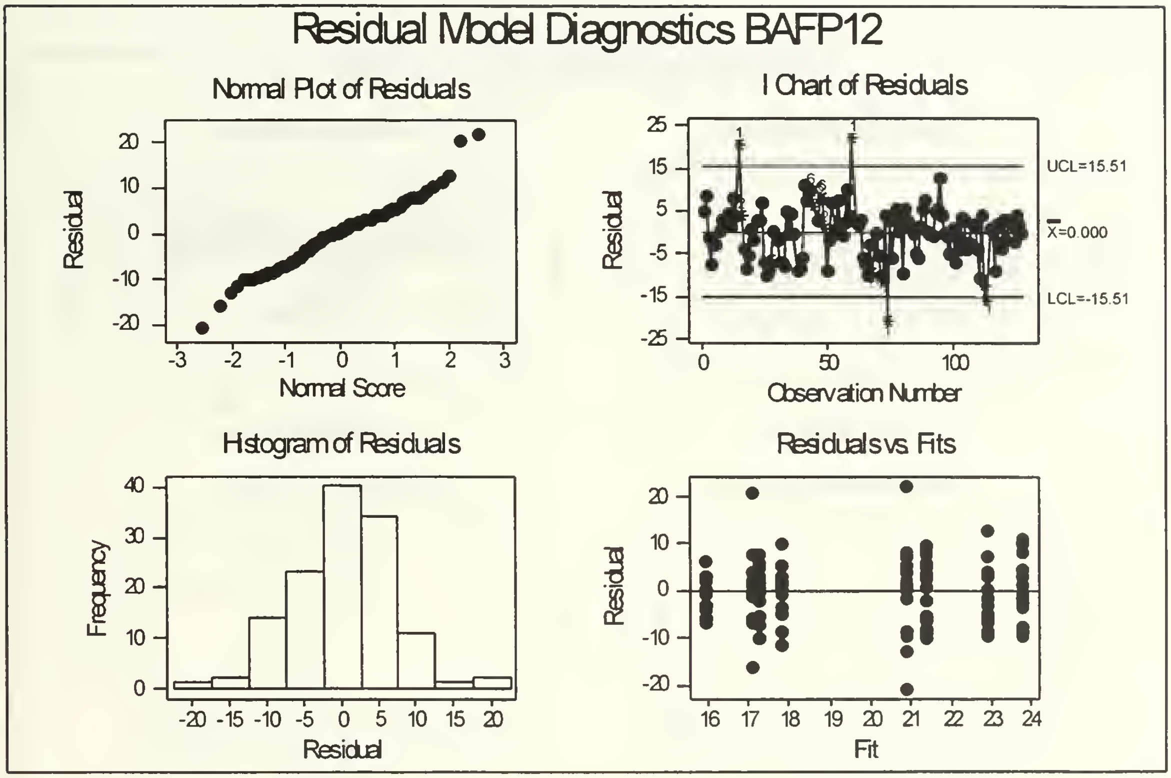

Figure 40. BAFP 12 Residuals Plots

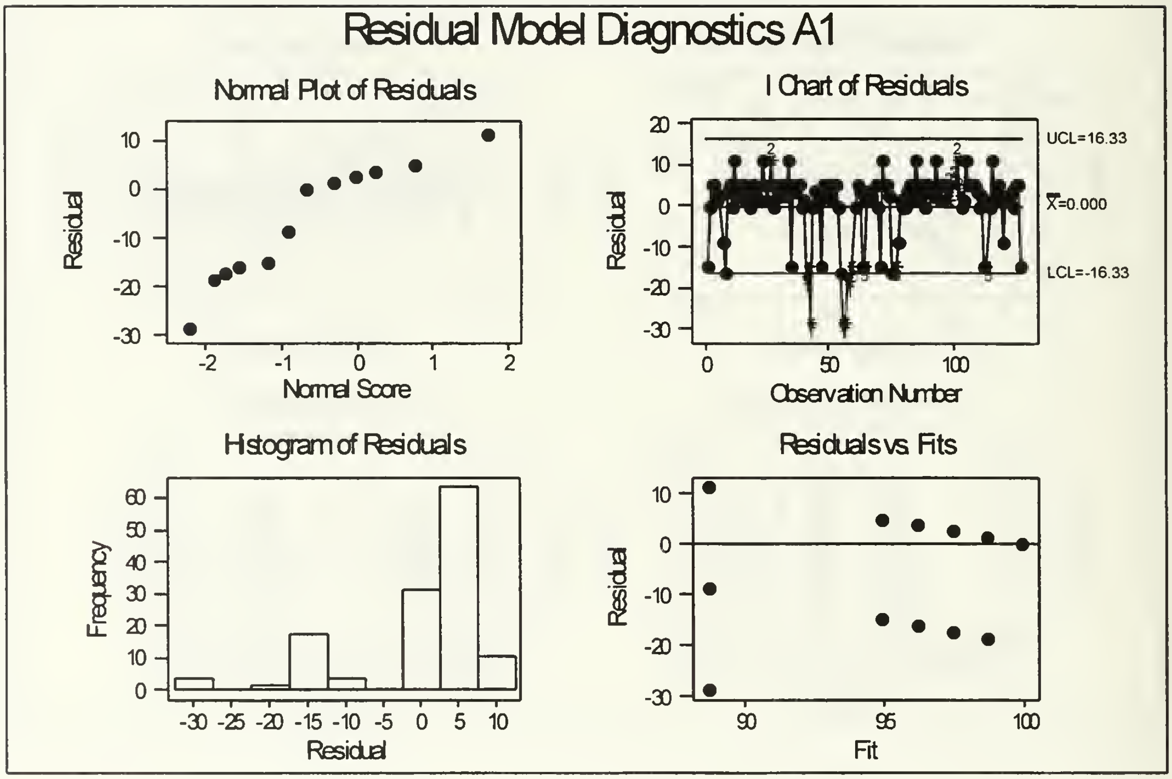

Figure 41. A 1 Residuals Plots

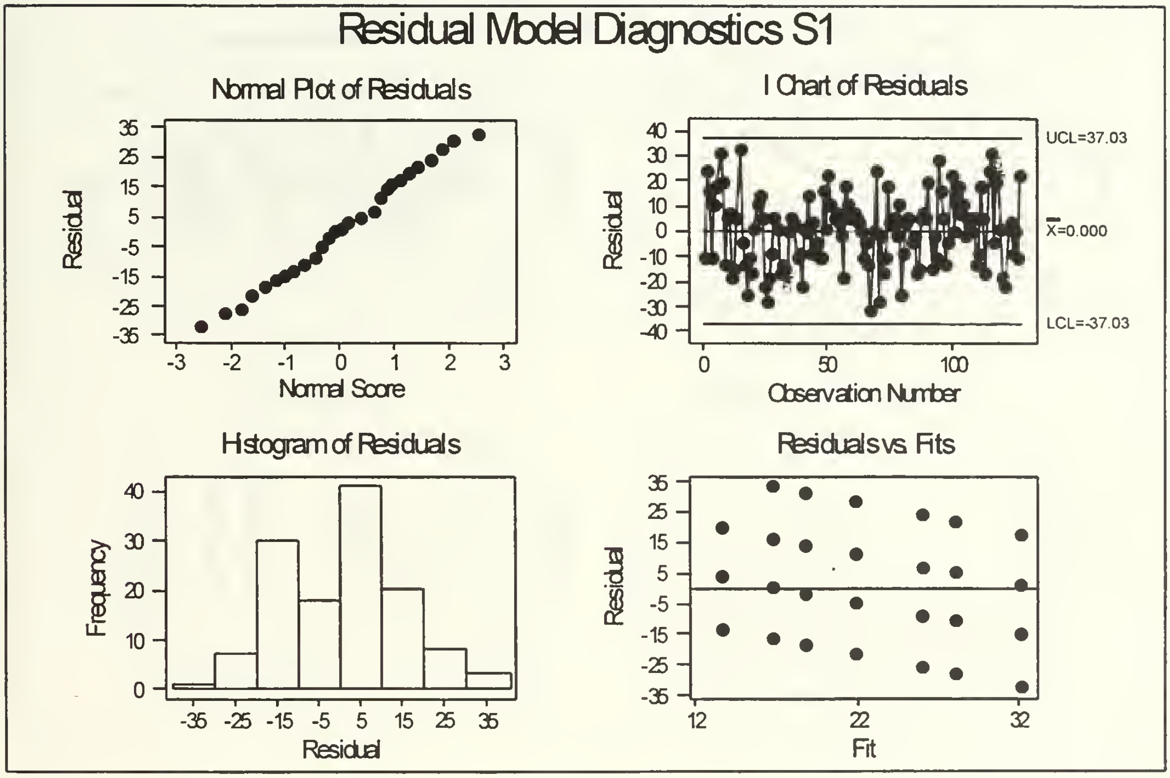

Figure 42. S 1 Residuals Plots

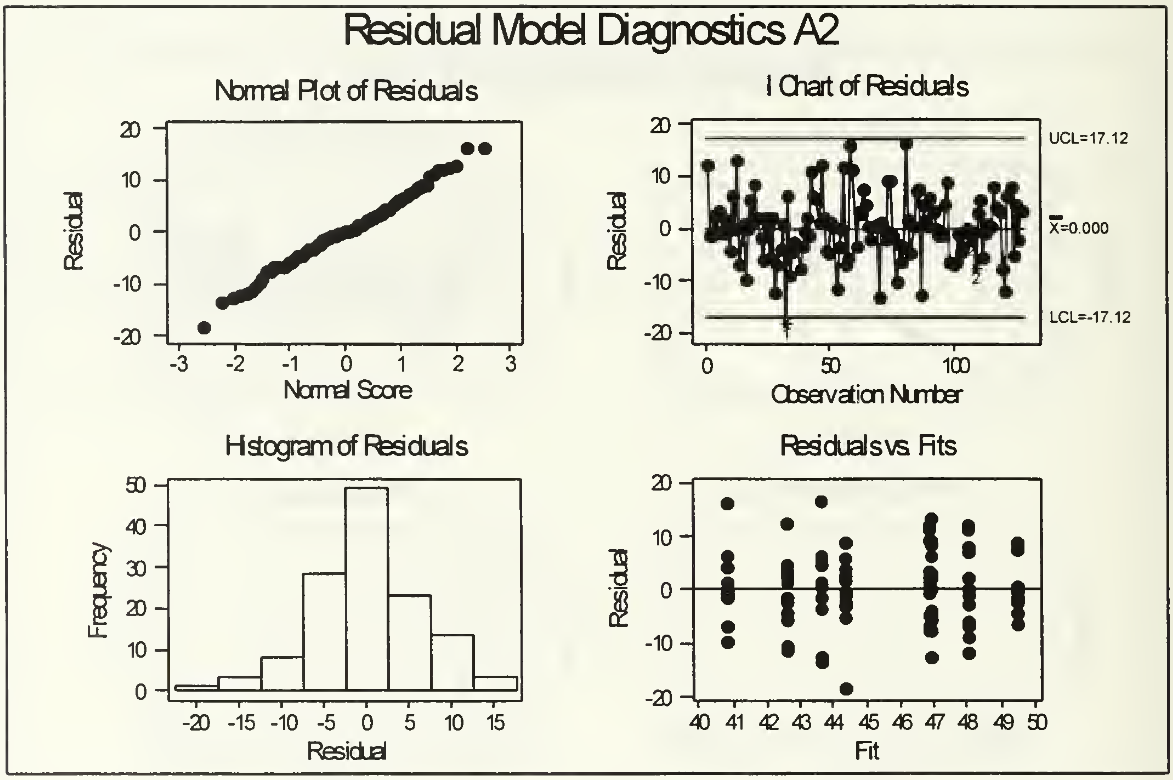

Figure 43. A 2 Residuals Plots

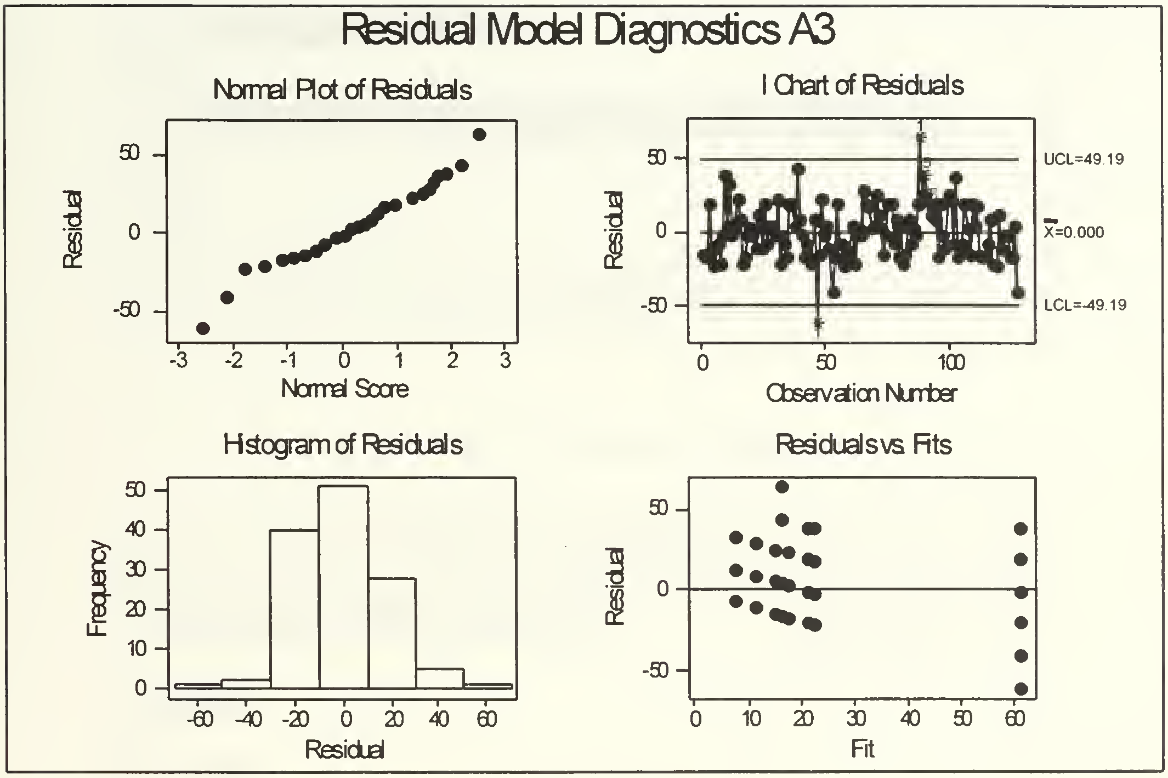

Figure 44. A3 Residuals Plots

APPENDIX G. DEMOGRAPHIC DATA

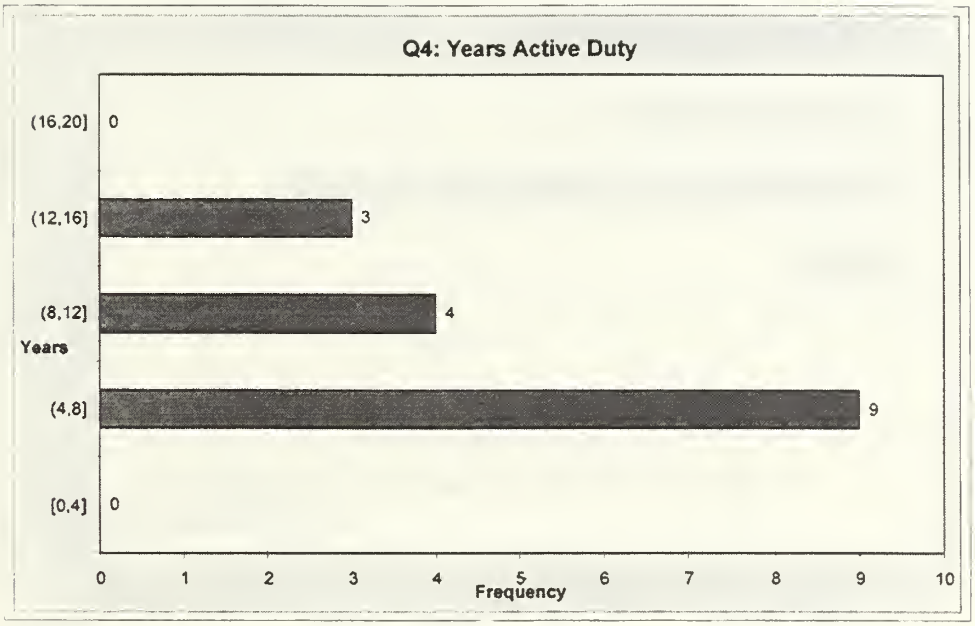

Figure 45. Q4: Years Active Duty

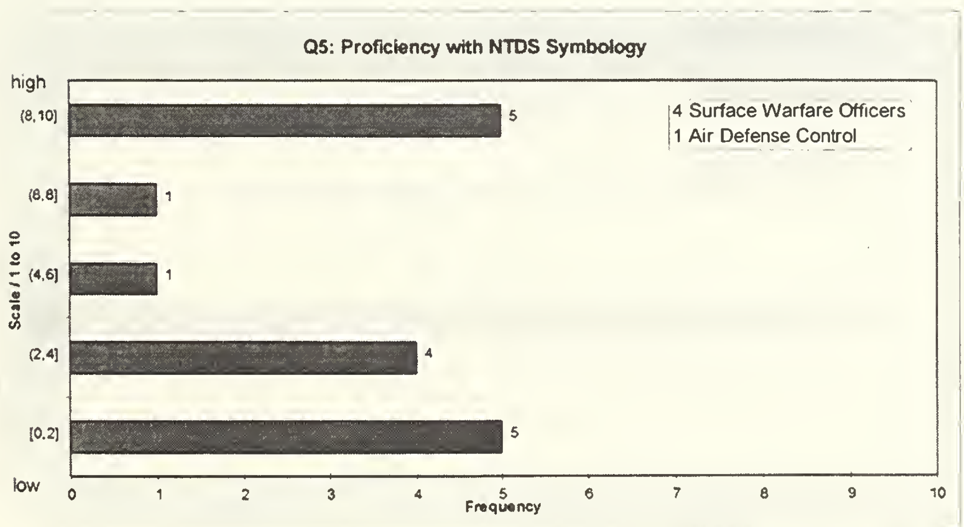

Figure 46. Q5: Proficiency with NTDS Symbology

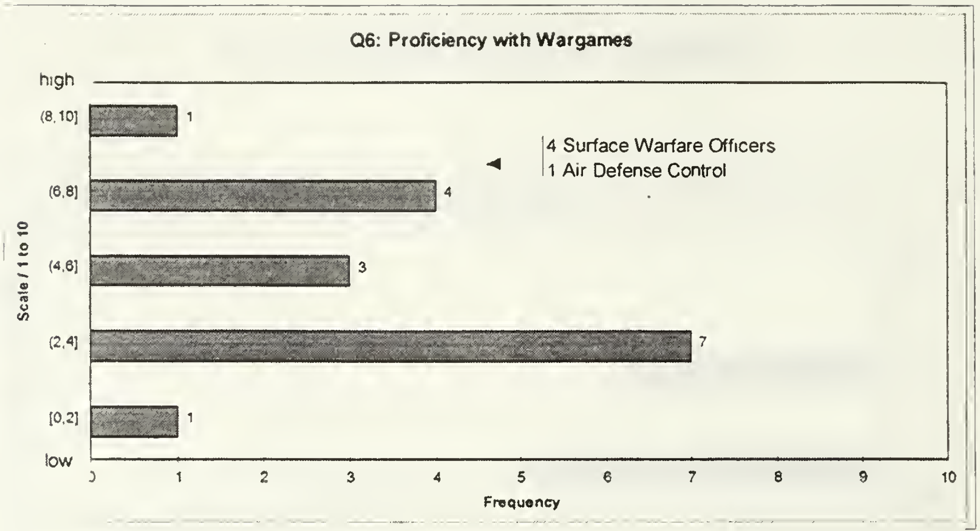

Figure 47. Q6: Proficiency with Wargames

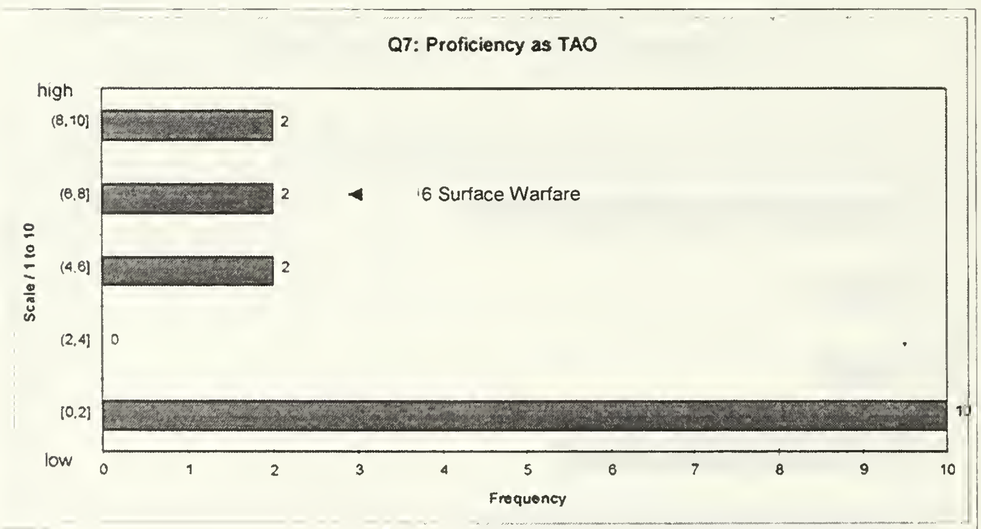

Figure 48. Q7: Proficiency as TAO

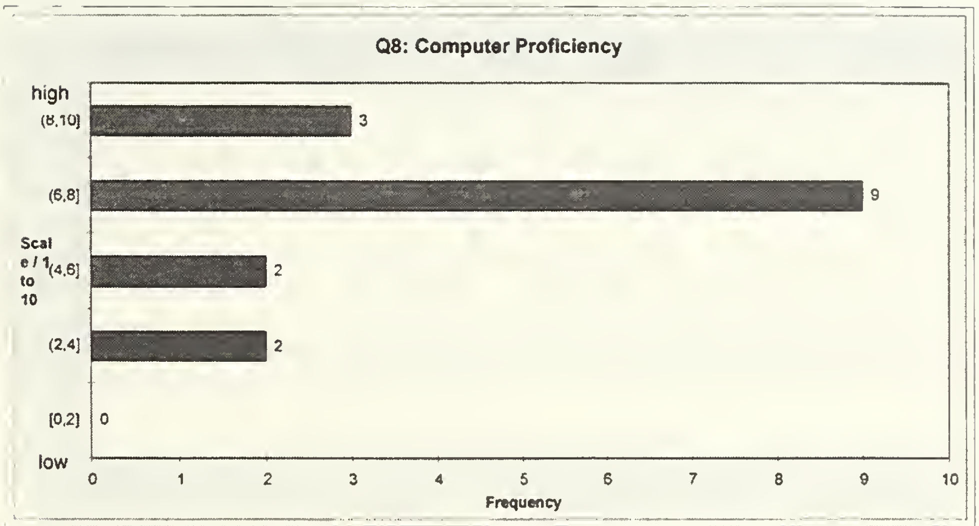

Figure 49. Q8: Computer Proficiency

APPENDIX H. NULL HYPOTHESES REJECTION SUMMARY

	BAFP1	BAFP2	BSP3	BSP4	BAFP12	A1	S1	A2	S2	A3
H_{01}				◆						
H_{02}		◆		◆						
H_{03}	◆	◆	◆	◆	◆	◆	◆			
H_{04}										
H_{05}				◆						
H_{06}								◆		
H_{07}		◆								

Note: Reading this table horizontally provides a summary of the PMs for which the given null hypotheses were rejected. Reading the table vertically provides an indication of the number of null hypotheses rejected for the given PM.

Table 1. Rejection Summary

APPENDIX I. NULL HYPOTHESES

H_{01}	Information Completeness has no impact on SAG performance.
H_{a1}	Information Completeness impacts SAG performance.
H_{02}	Work Load has no impact on SAG performance.
H_{a2}	Work Load impacts SAG performance.
H_{03}	FPB C^2 has no impact on SAG performance.
H_{a3}	FPB C^2 impacts on SAG performance.
H_{04}	The combined effect of Information Completeness and Work Load has no impact on SAG performance.
H_{a4}	The combined effect of Information Completeness and Work Load impacts SAG performance.
H_{05}	The combined effect of Information Completeness and FPB C^2 has no impact on SAG performance.
H_{a5}	The combined effect of Information Completeness and FPB C^2 impacts on SAG performance.
H_{06}	The combined effect of Work Load and FPB C^2 has no impact on SAG performance.
H_{a6}	The combined effect of Work Load and FPB C^2 impacts on SAG performance.
H_{07}	The combined effect of Information Completeness, Work Load and FPB C^2 has no impact on SAG performance.
H_{a7}	The combined effect of Information Completeness, Work Load and FPB C^2 impacts SAG performance.

Table 2. Null Hypotheses

LIST OF REFERENCES

1. U.S. Navy Dept., *"...From the Sea: Preparing the Naval Service for the 21st Century,"* Navy and Marine Corps White Paper, Washington D.C., September, 1992.

2. Huang, Alexander Chieh-cheng, "The Chinese Navy's Offshore Active Defense Strategy; Conceptualization and Implications," *Naval War College Review*, 1994.

3. Davies, Lieutenant Commander, U.S. Navy, Lieutenant Commander Collius U.S. Navy, "Armed Holo: The Future of ASUW," *Rotor Review*, Naval Helicopter Association, no. 50, Summer, 1995.

4. Ya'ari, Rear Admiral Yedidia Didi, Israel Navy, "The Littoral Arena; A Word of Caution," *Naval War College Review*, Vol. XLVII, No.2., Spring 1995.

5. Crawford, Lieutenant Commander K. R., U.S. Naval Reserves, Lieutenant M. T. Hatton, U.S. Navy, and Lieutenant Commander A. W. Melton, U.S. Navy, "Where Are the Littoral Warfare Fast-Attack Craft?", *Proceedings*, April 1995.

BIBLIOGRAPHY

Devore, Jay L., *Probability and Statistics for Engineering and the Sciences*, 3rd edition, Duxbury Press, Belmont California, 1991.

Federico, P. A., *et al.*, *Human Computer Interfaces for Tactical Decision Making, Analysis, and Assessment, Using Artificially Intelligent Platforms*, Naval Personnel Research and Development Center (NPRDC), San Diego, California, 1991.

Hughes, W. P., *Fleet Tactics*, Naval Institute Press, Annapolis Maryland, 1986.

Perla, Peter P. *The Art of War Gaming*, Naval Institute Press, Annapolis Maryland, 1990.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center 8725 John J. Kingman Rd., STE 0944 Ft. Belvoir, Virginia 22060-6218	2
2.	Dudley Knox Library Naval Postgraduate School 411 Dyer Rd. Monterey, California 93943-5101	2
3.	President of the Naval War College Code 1E211 Naval War College 686 Cushing Rd. Newport Rhode, Island 02841-1207	1
4.	President of the Naval War College Code 1C4 Naval War College 686 Cushing Rd. Newport Rhode, Island 02841-1207 Att. Commander Sweitzer	1
5.	Director Department Head Combat Systems Surface Warfare Officers Schools Command Code 30 446 Cushing Rd. Newport, Rhode Island 02841-1209	2
6.	Director of Curriculum Tactical Training Group Pacific 53720 Horizon Dr. San Diego, California 92147-5087	1

7. Joe Raby 1
Tactical Library
Tactical Training Group Pacific
53720 Horizon Dr.
San Diego, California 92147-5087

8. Command Officer 1
Helicopter Anti-Submarine Light Wing
U.S. Pacific Fleet
Naval Air Station, North Island
POB 357137
San Diego, California 92135-7137

9. Commanding Officer 1
Helicopter Anti-Submarine Light Wing
U.S. Pacific Fleet
Central Technical Publications Library
Naval Air Station, North Island
POB 357137
San Diego, California 92135-7137

10. Commanding Officer 1
Sea Based Weapons and Advanced Tactics School
Naval Air Station, North Island
POB 357048
San Diego, California 92135-7137

11. C3 Academic Group 1
Code CC
Naval Postgraduate School
Monterey, California 93943-5101

12. Professor Michael G. Sovereign 1
Department of Operations Research, Code OR/Sm
Naval Postgraduate School
Monterey, California 93943-5101

13. Professor Gary R. Porter 2
C3 Academic Group, Code CC/Po
Naval Postgraduate School
Monterey, California 93943-5101

14. Professor William G. Kemple 1
Department of Operations Research, Code OR/Ke
Naval Postgraduate School
Monterey, California 93943-5101

15. Professor Wayne P. Hughes, Jr. 1
Department of Operations Research, Code OR/Hl
Naval Postgraduate School
Monterey, California 93943-5101

16. Susan G. Hutchins 1
C3 Academic Group, Code CC/Hs
Naval Postgraduate School
Monterey, California 93943-5101

17. Pat-Anthony Federico 2
Naval Personnel Research & Development Center Code 13
5335 Ryne Rd.
San Diego, California 92152-7250

18. Lieutenant Nicholas K. Vodantis 2
11178 Portobelo Dr.
San Diego, California 92124